Report of the Highway 407 Safety Review Committee

1. PROJECT INFORMATION

1.1 Foreword This report documents a safety review of a significant highway project prior to its opening. The mandate of the Highway 407 Safety Review Committee was to carry out the review from a safety perspective, and we did not attempt to examine such broader considerations as levels of service and economics. Nor did we examine questions of responsibility, authority, legal obligation, or related matters, since these were neither relevant to a safety evaluation of the road, nor to the technical mandate of our committee.

Our findings address two interrelated issues:

- adherence to standards; and
- road safety issues related to the application of those standards to Highway 407.

Both are presented. They are equally important. Recommended actions are provided in each case.

Finally, we stress that the instructive advice from this review can be applied more broadly than just to Highway 407. Our findings also touch on issues relating to the way in which road safety is considered during the highway design process generally. We have deliberately chosen to express our opinions on this issue clearly and unequivocally. This part of our work is aimed at the highway engineering design community at large. It is our hope that they will read, understand, and translate this message into direct action so that safety is considered explicitly in the design process.

1.2 Name and extent of the project The project comprised a review of Highway 407 in the Province of Ontario from Highway 410 at the westerly limit to Highway 404 at the easterly limit. The length of the section of highway reviewed was approximately 36 kilometres (km). Both the main roadway and interchange elements (see Glossary, Appendix A) of this section were included in the review.

1.3 Project description This project is the first public-private partnership in Ontario for a highway of this type. The owner of the highway is the Ontario Transportation Capital Corporation (OTCC) and the developer is Canadian Highways International Corporation (CHIC). These parties are described further in Chapter 5 of this report.

The 36km section of Highway 407 reviewed is part of an overall 69km route. This section is expected to be developed in three phases. For design purposes, it has been classified as a rural freeway divided (RFD), with a mainline design speed of 120km/h. In the initial phase of its development, it is a controlled-access freeway providing three continuous lanes in each direction. A number of interchanges are provided with other freeways and major arterial roads on the surrounding street network.

The freeway will evolve from this initial stage to a 10-lane (five in each direction) facility, at which time the road will be essentially urban in character in terms of its environment and cross-section features. Additional interchanges may be developed as the freeway evolves through Stages 2 and 3 of its development. Our review focused mainly on the physical design and construction of the road as presented in Stage 1.

A plan of the section of Highway 407 reviewed, intended to illustrate its physical extent and general relationship to the surrounding road network, is provided in Appendix B.

1.4 Ontario Provincial Police involvement This review was initiated partially as a result of several concerns raised by the Ontario Provincial Police (OPP). The committee met with the OPP in order to obtain a better understanding of their concerns. Many of these concerns and other issues arising from our review are addressed in Chapter 6 of this report.

1.5 The safety review committee mandate The mandate of the PEO Highway 407 Safety Review Committee, as adopted by the PEO Executive Committee, is presented below.

1. *The Committee will undertake an independent safety review to address whether appropriate engineering standards were used in the design of Highway 407. This would include a review of the design issues raised by the Provincial Auditor and the Ontario Provincial Police.*
2. *The Committee will also address the appropriateness of the outcomes of the value engineering exercise on the design of Highway* 407.

In carrying out its work, the Committee will:

- *determine whether the highway meets or exceeds Ontario standards which have a bearing on road safety;*
- *determine whether the standards used and the design decisions taken in the design of the highway were applied in a manner which appropriately addressed safety;*
- *determine whether cost-effective opportunities were taken to enhance the highway's safety;*
- *consider whether there are any seemingly cost-effective opportunities to enhance the safety of the highway which merit consideration by the Ministry of Transportation.*

2. COMMITTEE RESOURCES

2.1 Committee membership

The Highway 407 Safety Review Committee is a committee of the Association of Professional Engineers of Ontario (Professional Engineers Ontario or PEO). It was formed by the association once the decision was made that PEO would carry out the review. The association's selection criteria required that committee members have:

- extensive expertise in various relevant aspects of highway engineering, design, traffic engineering and road safety;
- no prior involvement with the Highway 407 project; and
- no preconceived opinions on the safety or other aspects of the highway.

The selection of six professional engineers for the committee was announced January 10, 1997. The committee membership is listed below.

- **John Robinson, Ph.D., P.Eng. (Chair)**, Senior Associate, Transportation, UMA Engineering Ltd.
- **Brian Allen, Ph.D., P.Eng.,** President, AT Traffic Safety Corporation and Associate Professor, Civil Engineering, McMaster University, Hamilton, Ontario.
- **Ezra Hauer, Ph.D., P.Eng.,** Professor, Department of Civil Engineering, University of Toronto.
- **Frank Navin, Ph.D., P.Eng.,** President, Hamilton Associates, Vancouver, British Columbia, and Professor, Civil Engineering, University of British Columbia.
- **Arthur Scott, P.Eng.,** Transportation Consulting Engineer.
- **Gerry Smith, P.Eng.,** Director of Transportation, UMA Group.

In addition to these individuals and members of their supporting staffs, the committee called on two external specialists to assist in their work:

- Francine Constantineau, P.Eng., a value engineering expert with Valorex Inc., Montreal, Quebec.
- Alison Smiley, Ph.D., a human factors specialist with Human Factors North, Toronto, Ontario.

Further information on committee members may be found in Appendix C.

2.2 Process overview The committee began its deliberations on January 20, 1997. At that time, the committee set out its workplan, which included the following key activities:

- **review of relevant design documentation**, including: construction plans and specifications, design criteria, preliminary and predesign documentation where available, value engineering efforts by the two private-sector project proponents, the evaluation report on these efforts, the request for proposals, high-mast lighting planning studies, the engineering and design portion of the winning proposal, and other relevant design documentation;
- **reviews of Ministry of Transportation of Ontario (MTO) documentation** dealing with various technical issues related to the design of the facility;
- **background research** and analysis on technical issues arising from both of the above;
- **a series of on-site field assessments** by committee members and supporting specialists;
- a series of stakeholder meetings; and
- **analysis and development of findings**, recommendations and this report.

Throughout the process, excellent cooperation and support were received from both the Ontario Transportation Capital Corporation (OTCC) and the Ministry of Transportation of Ontario.

2.3 Supporting reference material

Over 100 documents relating to the design were reviewed by the committee and its support staff. A detailed list of these reference documents is provided in Appendix D to this report.

2.4 Site visits

Approximately six site visits were carried out, both by the committee as a group, and by individual committee members and supporting specialists. Initial visits were for familiarization purposes. Subsequent inspections were generally oriented to the investigation of particular questions of interest.

2.5 The role of PEO

The Association of Professional Engineers of Ontario, known as Professional Engineers Ontario (PEO), is the association that governs and sets standards for professional engineering in Ontario under the Professional Engineers Act. PEO currently licenses about 60,000 professional engineers in the province, as well as issuing Certificates of Authorization to corporate engineering practices in Ontario. In addition to its licensing function, it is responsible for ensuring the quality of engineering practice delivered to the public by its member engineers. It also undertakes the necessary disciplinary functions in the event of a breach of conduct by a member or company. It is comparable to the College of Physicians and Surgeons of Ontario for medical doctors in the province or the Law Society of Upper Canada for lawyers in Ontario.

The association has defined a leadership role for itself in society, committing to participate in public debate and policy setting where protection of public health, safety and welfare involves the use of engineering principles. It is in this role that the association was commissioned by the Ministry of

Transportation of Ontario to strike an independent committee of experts to carry out the Highway 407 Safety Review.

2.6 How this report is organized

In writing this report, we've tried to provide a balance of hard technical information with supporting explanations of some of the more contentious issues. To help readers better understand road safety in the context of highway design, we've provided Chapters 3 and 4. The former states what we believe to be true about the relationship between road safety and highway design. It discusses some basic concepts of road safety, and tries to leave the reader with an understanding of what can reasonably be expected from a safety review. The latter takes a lay person's look at the highway design process. The aim is to give people who are unfamiliar with highway design a look at what this work involves. Here, we stress the important differences between highway design and other more conventional and structured design processes. Chapters 5, 6 and 7 describe our findings. Chapter 5 discusses the development of Highway 407, as well as our review of the construction plans and associated documents. It attempts to answer the question of whether the Highway 407 design complies with current Ontario standards. Chapter 6 looks in more detail at a number of specific and sometimes contentious technical questions. It is this chapter that examines the road safety issues related to the application of current Ontario practices and standards to Highway 407 in particular. Chapter 7 discusses the implications of the value engineering exercise for road safety. Chapter 8 contains information on how to build safety into a road. Chapter 9 ties our findings together, interprets what they mean, and provides a set of recommendations. It is in this chapter, as well, that we extend the lessons learned in our review of Highway 407 to the broader context and community of highway designers.

3. ROAD SAFETY REVIEW PRINCIPLES

3.1 Preamble To convey our message clearly, we need to state at the outset what we believe to be true about safety in road design.

3.2 There are no safe roads

A road would be completely safe if no collisions occurred on it. But crashes occur on all roads in use. It is therefore inappropriate to say of any road that it is completely safe. However, it is correct to say that roads can be built safer or less safe. Consider two alternative road designs, connecting the same two points and carrying the same traffic. The road design that is likely to have fewer or less severe crashes would be deemed to be the safer one.

3.3 The nature of safety improvements

We know how to make a road safer. Building a wider median, placing obstacles farther from the travelled lanes, providing more pavement friction, designing curves with larger radii, etc., all make for safer roads. Typically, safety changes gradually as some dimension of the road or of the roadside changes. Therefore, it makes little sense to say, for example, that if obstacles are 9 metres (m) from the edge of the travelled lane the road is unsafe, but if they are 10m from it, the road is safe. What is true is that the farther an obstacle is from the edge of the travelled lane, the fewer and less severe collisions with it are likely to be.

Some safety improvements are not gradual. Thus, for example, the decision to illuminate the road will cause an abrupt drop in nighttime collisions and a (usually smaller) increase in daytime collisions with light poles or the barriers in front of them.

3.4 Diminishing marginal benefits

Safety improvements are usually subject to the law of diminishing marginal returns. This means that for every improvement of a fixed amount, the safety benefit gained decreases a little each time. For example, increasing the width of the median from 50m to 60m will decrease the number of collisions less than increasing it from 10m to 20m. Eventually, a width will be reached at which widening the median further cannot be justified because the improvement in safety is too small.

3.5 A possible objection?

Some people may object to the judgment that a point exists beyond which further improvement in safety is not justified, claiming that any improvement in safety is worthy. This position, we think, is not tenable. Expenditure of public money can save life and limb in many places in Ontario. However, spending the budget where it saves few lives means that some lives will be unjustifiably lost by not spending it where more lives could have been saved.

3.6 Knowledge, judgment and standards

Knowledge of how the features of a road affect safety is imperfect. Some road features are well-researched and their effect on safety can be expressed by numbers. For other, less well-researched features, only the direction of their effect on safety is known. There are even road features the effect of which on safety is at present unclear. It must be understood that the relationship between road features and safety is not known with the kind of precision that is customary in the physical sciences and in engineering disciplines that allow experimentation.

As a result, one must leave room for judgment and legitimate differences of opinion. One must not think that it is always possible to determine by calculation the point beyond which further improvement in safety is not cost-effective. The hope is that the collective professional judgment about safety, economics and other matters is reflected in the engineering standards and practices used in road design. Indeed, road design standards and practices are the product of accumulated experience and written by committees of experts in road design. As such, road design standards capture what is agreed upon to be good practice by the members of the committee at the time the standard is written.

3.7 Road design standards and safety

At this point, a difficult problem of communication arises. In English, "meeting a standard" is understood to be a guarantee of quality; conversely, if something is "substandard", it is understood to be deficient. **This meaning does not apply to safety in road design standards.** To explain why, three essential aspects of the complex relationship between road safety and road design standards are discussed below.

First, as mentioned earlier, the safety of a road does not change abruptly when some road feature changes slightly. Consider, for example, the current design standard stipulating that the length of an acceleration lane (see Figure 3.1) has to be at least 500m.

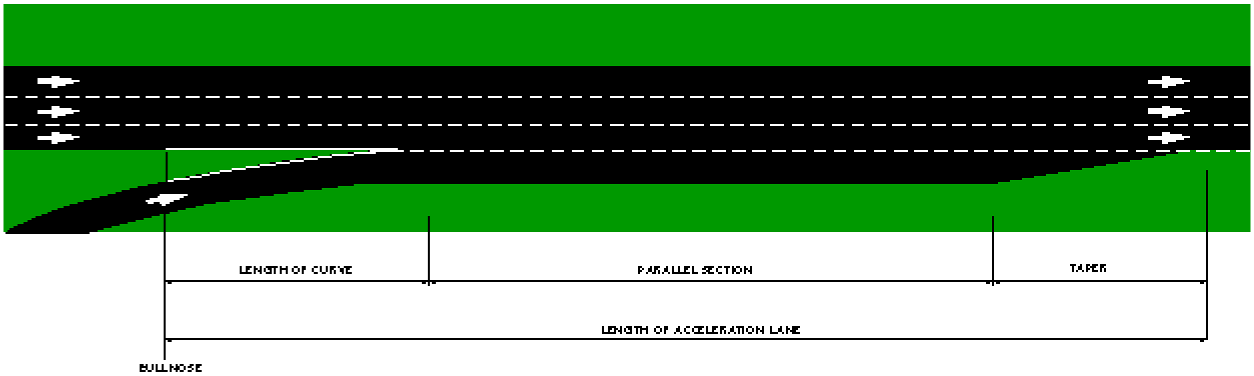


Figure 3.1. Freeway acceleration lane

An acceleration lane that is 490m long is not unsafe; it will be, perhaps, only slightly less safe than a 500m-long acceleration lane. Thus, **not meeting a standard does not necessarily make a road unsafe.**

Second, many highway design standards are limit standards, which means that for a certain class of road, the radius of a horizontal curve has to be at least "x" metres long, a roadside obstacle must be at least "y" metres from the edge of the outer lane, the grade must be at most "z" per cent, and so on. Just meeting such a standard does not make the road as safe as it can be; if a radius larger than "x" is chosen, if obstacles are placed farther than "y" from the travelled lane and if the road grade is less than "z", the road would be safer. **Thus, the aim of good design practice is to exceed the limit standard, not just to meet it.**

Third, road design standards evolve with time. Roads used to be made with lanes 3.6m (12 feet) wide; now the standard calls for 3.75m-wide lanes. This does not mean that the entire old stock of roads with 3.6m lanes is unsafe. Similarly, crest vertical curves over hills used to be designed so that the driver could see in time to stop safely before hitting an obstacle more than 150 millimetres (mm) high in the path of the vehicle. Nowadays, the standards say that only obstacles 380mm or higher need to be seen in time. Thus, by the current standard, obstacles less than 380mm high in the path of a vehicle may not be visible in time for a safe stop. This does not mean that roads designed with the 380mm obstacle in mind are unsafe. It means only that **the information, judgments and economic considerations that go into formulating design standards change over time.**

Road design standards are not the demarcation line between safe and unsafe. They are a reflection of what a committee of professionals of that time considers to be good practice.

3.8 Prevention, not fault

Consider the following invented sequence of events. A driver was going north on an arterial road at 70 km/h, where the speed limit is 50 km/h. He intended to take the inner loop ramp (see Figure 3.2) onto a freeway to travel west. This ramp has a tight curve, turning right, that has a 50 km/h design speed. The posted advisory speed on the curve is 30 km/h. The driver apparently misperceived how much deceleration was needed to negotiate the curve and the vehicle skidded to the left. Since there is no guiderail at this point, the vehicle rolled down the embankment. The embankment is a drop of 5m over a horizontal distance of 15m.

Figure 3.2. Arterial-to-freeway inner loop ramp

The rear door opened, an unbelted child was ejected and severely injured.

Clearly, the driver was "going too fast for the conditions" and the child should have been wearing a seat belt. But fault or culpability is not the issue here. For the highway designer, the question would be: "What might help prevent collisions of this kind or reduce their severity?" If we could make drivers go slower at this site and help them perceive what deceleration is needed, and if the curve were built less tight, (i.e. had a higher design speed been chosen), fewer vehicles would run off the road on this ramp. If a guiderail were placed along the entire curve, some skidding vehicles would be prevented from tumbling down the embankment. Even if there were no guiderail, but the embankment had been built to be less steep, some vehicles might not overturn going down the slope. If vehicles were made so that doors were less likely to open when the vehicle rolled, there would be fewer ejections of occupants. If we could induce more occupants to wear seat belts, this, too, would reduce the chance of ejection and injury. All of these and several other actions might have altered the course of events and the final outcome. However, only some of these actions would be within the direct purview of the highway designers. At this site, the designer should examine at least:

1. the choice of the design speed (and the resulting minimum radius of the ramp curve);
2. the decision of where guiderails would be placed; and
3. the design of embankment slopes.

Obviously, the driver's "human error" played a major role in this invented story, as it does in most real collisions. This leads many to think that road users ought to be the sole target of preventive measures. Among road safety professionals, however, such thinking is widely recognized as incorrect. The fact that almost all collisions could have been prevented had those involved acted differently does not mean that the most effective way to reduce collisions is to alter people's behaviour or tendency to make errors. Effective action must aim jointly at the human element, the vehicle and the road. Road design can reduce the incidence of human error and the chance that human error will result in a collision, and can ameliorate the severity of the consequences of collisions that are initiated by human error.

3.9 Comments and questions

In this chapter, we have described our view of road safety in highway design. In summary, we think that roads can be built safer or less safe, but that a road cannot be classified simply as being either safe or unsafe. Meeting minimum standards does not guarantee that a road is sufficiently safe. Conversely, not meeting a minimum standard does not necessarily imply that the road is unsafe.

We often know the direction in which safety is likely to change if some road design feature is altered. However, current knowledge about the amount of safety gain or loss that comes from a change in some road feature is imprecise. Also, the design choices engineers make imply trade-offs between life, limb and economics, a judgment that is at best difficult.

In view of these beliefs and the circumstance of this review, we chose to answer the following questions.

- *Does Highway 407, as built, meet or exceed the prevailing Ontario design standards that have a bearing on road safety?*

This question is raised because the public debate has been couched in similar terms and therefore an answer will be expected.

- *Were the standards used and the design decisions made in a manner that appropriately addresses safety?*
- *Were cost-effective opportunities to enhance the safety of Highway 407 examined and exploited during its design?*

We chose to raise these questions because meeting minimum standards does not mean that the road is sufficiently safe and not meeting minimum standards does not necessarily imply important safety omissions.

- *What seemingly cost-effective opportunities to enhance the safety of Highway 407 exist now?*

This question must be answered to ensure that no reasonable measures to enhance public safety are overlooked.

4. **HIGHWAY DESIGN PRINCIPLES**

4.1 What is design?

Design is the process of selecting the elements that once combined will make up an end product. In engineering, these elements are primarily features, dimensions and materials. Highway geometric design is selection of a road's visible features and dimensions (lane or shoulder width, for example). These have important bearing on how the road will function, its capacity, driver behaviour and safety.
Design is an activity in which judgment and experience play significant roles. Designers choose the features of the road and dimensions of the primary design elements. They may use judgment, guidelines, standards and calculations to assist in selecting the appropriate primary design elements. Because of the nature of this process, the design that emerges from it cannot be called "correct" or "incorrect", but rather "better" or "worse".

4.2 The designer's toolkit

Designers and engineers have several tools they can use in designing a final product. Among the most important of these are the designer's own experience and training. In addition, designers can refer to design standards, to publications on related topics and to similar previous design projects. The experience of the designer's colleagues and peers is also an important resource for the designer.

4.3 The role of standards

Engineering standards are important tools to help designers generate superior designs. However, it is important to understand that engineering standards do not determine the dimensions for any given design. That is the designer's responsibility. The role of design standards is to provide information and background to assist the designer in choosing the appropriate features, dimensions and materials for a given design. Minimum standards represent a lower limit (minimum width, for example). Designers should not go below these minimums without explicitly justifying why. Certainly, the standards a designer refers to in preparing a design will influence the design, but the final design is the sum of all of the decisions taken during the design process.

Highway design standards are necessarily general, because they cannot cover all site-specific conditions. They are based on prevailing and predicted vehicle dimensions and performance, and current technologies. Because these will vary with time, standards are revised and updated periodically. How standards are applied depends on transportation characteristics and on such site-specific features as terrain and adjacent development.

4.4 Applying standards in design

Highway design standards cannot cover every condition or situation that may be encountered. If standards are applied without considering local conditions, they may generate a satisfactory product, but there is no assurance. In applying standards, designers may modify a dimension indicated by the standards to account for local conditions. Sometimes, a design with more generous dimensions will result; sometimes, a design with dimensions that are lower than the standards may be appropriate.

Simply put, dimensions that do not meet standards are not necessarily unacceptable - and dimensions that meet standards do not guarantee an acceptable design. In assessing the quality of an existing design, it is not appropriate simply to consider a checklist of standards. The design has to be reviewed with judgment; standards merely assist the reviewer in making those judgments.

Applying standards and practices without considering prevailing circumstances is no substitute for judgment, and brings no assurance of an acceptable end product. Equally, designs prepared without referring to generally accepted standards and practices are not likely to serve the travelling public as intended. Designs based on a combination of sound professional judgment, applicable standards and current practices will generate the most effective highway.

Highway design standards are intended to provide comfort, safety and convenience for the travelling public. They are developed to take into account environmental quality-and the effect of a road on the environment can often be mitigated by thoughtful design. This approach, coupled with the principle of a design that blends visually with the surrounding terrain or setting, will usually produce roads that are acceptably safe and efficient for users, and that non-users find environmentally acceptable.

4.5 The design challenge

Within any design, there will be competing alternatives that must be thoughtfully considered to arrive at the best solution; this is the design challenge. For example, in a situation where the desire is to provide a high level of service and to minimize cost, a six-lane freeway will provide a better level of service than a four-lane freeway; however, the six-lane freeway will be more costly than the four-lane freeway. The choice between the additional service and higher cost, or the reduced service and lower cost, is a decision that is not only technical, but also political in nature.

The same approach applies to matters of safety. Almost all designs can likely be modified to produce a safer facility, but there is a societal cost attached. Whether that cost is appropriate and acceptable is a matter of judgment, rather than simply a matter of evaluating which of two designs is "correct" or "incorrect".

In general, the more generous a highway design's dimensions are, the safer the road will be; however, no matter how generous the dimensions, it is impossible to make a road completely safe, if by "safe" we mean a road on which we can guarantee that there will never be a collision. We can, however, design a road to provide a reasonable level of safety. Just what is a reasonable level of safety, when we take into account the cost required to build it, is a matter of experience and judgment. In short, the notion of a "safe" road is largely a myth. Design should be viewed instead as a process whereby we can make roads "more safe" or "less safe".

4.6 The design objective

A well-designed road will provide the intended level of service, at an acceptable cost, with an acceptable level of safety. It will also reflect local values and policy, which will vary from location to location. If it has been designed with care and sound judgment, it will place appropriate importance on safety, cost, service, environmental values, and appearance.

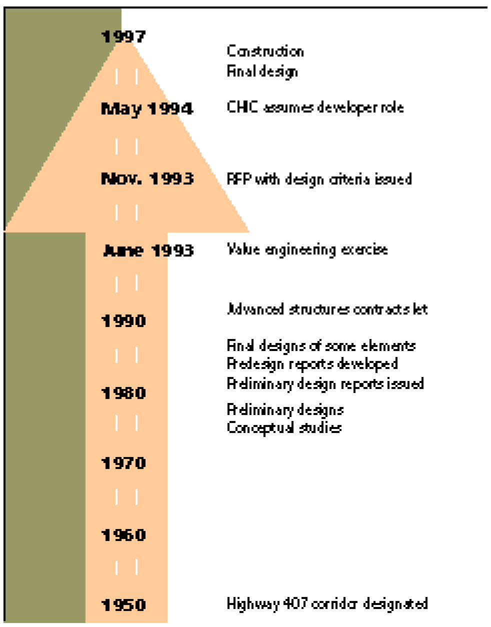
5. FINDINGS - DESIGN REVIEW OF HIGHWAY 407

5.1 Design review framework The committee undertook a detailed safety review of the design elements of the project with two objectives in mind:

- to address the first part of our mandate in assessing the compliance of Highway 407 to current standards in the Province of Ontario; and
- to explore the broader questions of how well safety will be served by the physical features of the highway, and how forgiving the road will be to driver error.

We began our work with a review of the evolution of the design criteria for Highway 407. Elements of design criteria are listed in Table 5.2. This review helped us to put the design framework for the facility into its proper chronological and organizational perspective. Our actual design review - which begins in Section 5.3 of this chapter - took the form of a detailed examination of the construction plans, design criteria and other related documentation dealing with the physical design of the highway.

Figure 5.1. Design History of Highway 407



From a practical standpoint, it was both impossible and unnecessary to review every single aspect of the design. Thus, in carrying out this work, we conceived our review as covering all of the major elements of the design, and most of the minor elements. We directed our efforts at safety considerations only, rather than toward other such aspects of the design as service or economics.

The results of this review are presented in several locations. In Section 5.3 of this chapter, we provide a series of observations related specifically to individual features observed on the plans.

In Chapter 6, we provide additional discussion on a number of key design features of Highway 407. These discussions address the broader issues which have been raised in the media and elsewhere with respect to the design of this facility. They also supplement the design review, by providing a more detailed discussion of the relationship between current practices/standards related to specific features, and the implications these hold for road safety.

5.2 Background history

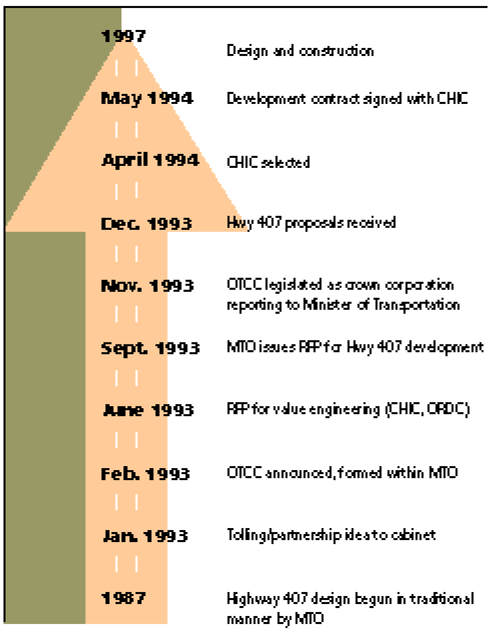
5.2.1 The historical context

The Ministry of Transportation was engaged in the planning and design of Highway 407 as far back as the 1950s when the highway corridor was first designated (see Figure 5.1). Work was well underway by the early 1980s. The ministry issued three preliminary design reports, in 1983 and 1984. Following the preliminary design, several components of the highway went to the predesign stage and then to final design. Several construction contracts for Highway 407 structures were initiated in the early 1990s.

In 1993, the Ontario government undertook to develop Highway 407 in a new and different manner: The private sector would assume responsibility for designing, building and operating the highway and the government would secure the funding to be recouped by tolls. The highway would be returned to the government after the end of the lease period.

In an effort to establish a more cost-effective highway design, the ministry commissioned a value engineering assessment of Highway 407 (discussed in Chapter 7). Two value engineering assessments were reviewed and evaluated by MTO and an independent engineering firm.

Figure 5.2. Organizational History



Both were used to develop the subsequent design framework for Highway 407. MTO then issued its request for proposals (RFP) for the design and construction of Highway 407 in September 1993, along with a set of amended design criteria based on the value engineering.

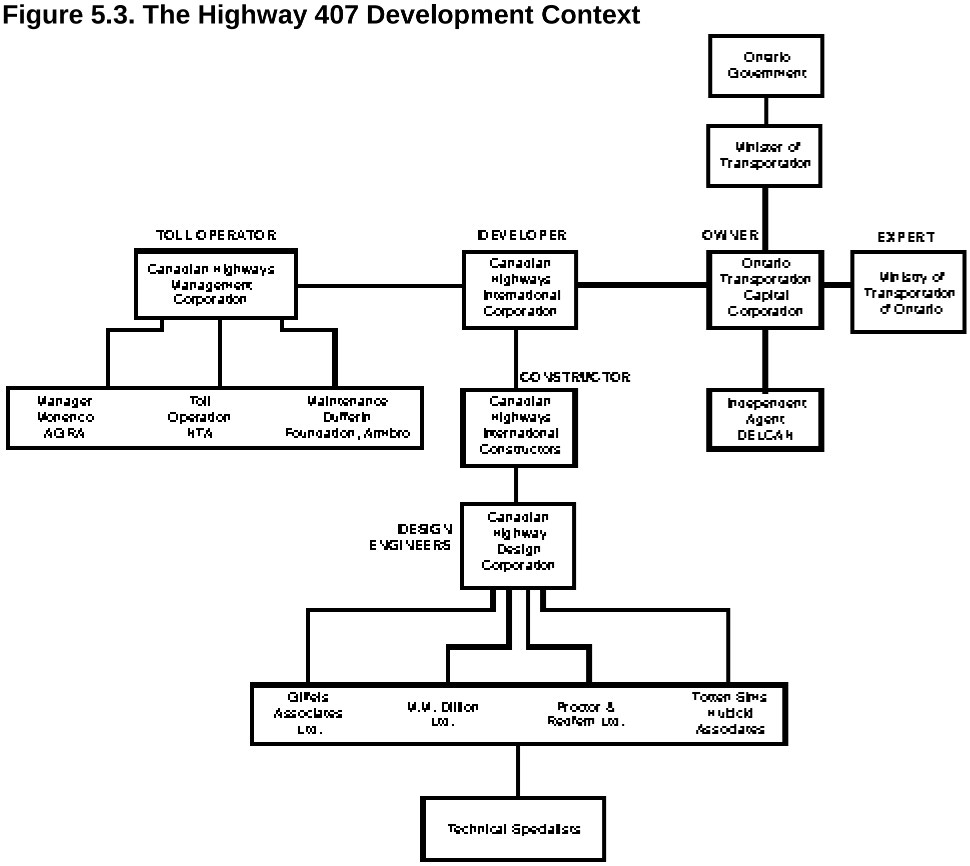
In April of 1994, the province announced the selection of Canadian Highways International Corporation (CHIC) as developers for Highway 407. Because this event occurred after the ministry had already initiated design and construction of the highway, the ministry retained control of the construction works in progress, and some elements of the design for structures or other works for which design was either near completion or in an advanced stage of final design. The balance of the project came under the aegis of CHIC.

5.2.2 Evolution of the partnership organization

The evolution of the partnership organization is shown in Figure 5.2. The government of Ontario started building Highway 407 in 1987, in the traditional method with annual funds being allocated to MTO. In 1993, it decided to seek a partnership for a Toll Highway 407. In February 1993, the Ontario Transportation Capital Corporation (OTCC) was announced and its staff assembled from within MTO. A request for proposals for a value engineering exercise, to more efficiently develop Highway 407 as a toll facility, was let in June 1993. Two firms responded: Canadian Highways International Corporation (CHIC) and the Ontario Road Development Corporation (ORDC).The value engineering reports were reviewed by MTO and an independent consultant (FENCO) and design criteria were established. The new design criteria and project scope were used in a request for proposals in September 1993 to partner for the toll highway.

The responses to the RFP were delivered to MTO in mid December 1993. These were evaluated by MTO and other ministries under the guidance of Price Waterhouse. The Decision Committee had deputy ministers from Transportation, Economic Development and Trade, Consumer and Corporate Affairs and Finance. All questions of policy were referred to Cabinet. The announcement that CHIC was the successful proponent was made in April 1994, and the final negotiated contracts were signed on May 10, 1994.During this time, the government had continued building Highway 407 in the traditional MTO method. The interchange structures at Highway 427 and Highway 400 were in progress and CHIC was required to work around this fact.

Figure 5.3. The Highway 407 Development Context



5.2.3. Organizational structure

The broad organizational structure to build Highway 407 is shown in Figure 5.3. The owner of the facility is Ontario Transportation Capital Corporation (OTCC). The developer is Canadian Highways International Corporation. The actual constructor is Canadian Highways International Constructors. The constructor was assisted by Canadian Highway Design Corporation, who was the design engineer, and a number of specialists. Operating the highway is the responsibility of Canadian Highways Management Consultants.

The owner had an independent agent, and for expert advice could call upon MTO. The major role of each organization is given in Table 5.1.

Table 5.1. Roles in Building Highway 407

Agency	Role
Owner (OTCC)	• the owner on behalf of the Government of
Independent agent (Delcan)	• validate progress payments • approve that designs met terms of contract • quality control and assurance
Expert (MTO)	• provide expert advice to questions submitted by OTCC
Developer (CHIC)	• develop Highway 407 • operate Highway 407 • maintain Highway 407 • transfer Highway 407 to OTCC after 35 years
Constructor (CHIConstructors)	• design Highway 407 • construct Highway 407
Design engineers (CHDC)	• design Highway 407 • construct Highway 407
Specialists	• provide specialty designs and advice
Operation (CHMC)	• maintain and operate Highway 407

5.2.4 Implications

The organizational heritage of Highway 407 is significant in its implications for the nature of the final design.

The developers of Highway 407 were required to design their portion of the facilities within an already well-defined design context. This context was created by the MTO-designed structures that were already in place and a number of design decisions that were taken during or before the preliminary design process and carried through the design/build exercise without further consideration. This framework limited CHIC's flexibility in creating its final designs in some areas. We discuss the implications of these limitations in specific terms in Chapter 6 of this report.

The organizational structure of the Highway 407 partnership changed the design criteria approval process normally used by MTO. The original design criteria were set for Highway 407 in the 1970s. These design criteria were reviewed and changed when necessary at a few stages in the process of designing the highway. The MTO sign-off procedure enumerated the design criteria, and then key engineers involved in the project signed the documents. The design criteria went through a formal MTO process initiated in the Regional Office, and then completed in the Highway Design Office. Before a review by the Highway Design Office could commence, the following regional engineers were required to sign-off on the proposed design criteria: district engineer, regional manager of engineering and right-of-way, regional manager of construction, and regional director.

The design criteria were then circulated to a number of ministry offices and to the Head Office Design Criteria Committee. In total, the signatures of five senior engineers were required to sign-off on design criteria. Several sections of Highway 407 were signed-off in 1991, under this process. Our review of the Canadian Highways International Corporation (CHIC) design criteria documents sign-off procedures for Highway 407 indicated that a total of three signatures were required. These included the CHIC project manager, OTCC and the independent agent. However, the design criteria documents provided to this committee show only the signature of the CHIC project manager. It is unknown whether the sign-off on the design criteria was completed in full elsewhere; if not, it is apparent the sign-off procedure was incomplete.

In reviewing the organization of the Highway 407 partnership, we had difficulties establishing which agency assumed the role of the "guardian of public safety". Although our discussion revealed that safety was implicitly considered by all agencies, we could find no single body or agency that acted explicitly as the arbiter of public safety. In the traditional process, this responsibility clearly lay with MTO. This was not necessarily the case in the partnership context. The apparent loss of a specific organization with the responsibility and authority to act on matters of road safety is of concern to this committee.

5.3 Design review commentary

The committee reviewed the elements of the design, to assess how well the design complied with prevailing standards. This was done through a review of the design plans, and covered all of the major elements of the design and most of the minor elements, as shown in Table 5.2. This review was not field verified or comprehensive. The review was directed at safety only rather than toward such aspects of the design as level of service or economics.

The findings of this review are presented in this section. Where we found the design satisfactory and have no concerns, this is stated without further discussion or explanation. Where there is concern about a feature, it is sometimes simply stated and in other cases elaborated on where it is felt this would be helpful.

Issues arising from the Highway 407 Safety Review are discussed in Chapter 6.

5.3.1 Design criteria

5.3.1.1 Classification

Classification of a highway facility gives direction to the designer in selecting appropriate design dimensions and preparing details. In the case of a freeway, the classification influences design speed, ramp radii, ramp superelevation, median width and treatment, and some drainage details.

Highway 407 was classified as a rural freeway for design criteria purposes. The words "rural" and "urban" refer primarily to the nature of the surrounding area and development and to some characteristics of the traffic. Trip length tends to be longer on rural freeways than urban freeways. Typically, rural freeways have less traffic and fewer lanes. Rural freeways typically have no more than four lanes and urban freeways have at least six lanes.

In view of the nature of the surrounding area of Highway 407 and the expected conditions during its first stage of operation, the rural classification is appropriate for the initial stage, in which the freeway has six lanes and a 22.5m median. However, accounting for the potential for growth in the vicinity of Highway 407 in the Toronto setting, Stage 2 (eight lanes) and Stage 3 (10 lanes) could be considered as "urban". It is common practice in highway engineering to plan and design with future stages in mind. In this case, the ultimate stage is a 10-lane highway with interchanges at most arterial crossing roads.

Although Highway 407 was classified as "rural", it appears that some of the design was carried out as though it were "urban", although this is not explicitly expressed in the design criteria. The request for proposals does not mention classification. The review of the value engineering exercise classifies Highway 407 as "rural".

Table 5.2. Framework for the Review of Design Plans

Feature Category	Constituent Elements
Design criteria	• classification • design speed • width and staging • illumination • bridge piers • sign supports

Alignment	• radius/superelevation
	• ramp geometrics
	  • entrances
	  • exits
	• horizontal sight distance
	  • bridge abutments
	  • bridge parapets

Profiles	• stopping sight distance • sight distance to bullnose
Typical cross-sections	• lane width • shoulder width • superelevation • crown location

Speed-change lanes	• exit terminals • entrance terminals
Lane balance	• exit terminals • entrance terminals • basic lanes • lane continuity
Signing and marking	• overall assessment
Illumination levels	• overall assessment

Protection for safety	• lighting poles
	• bridge piers, abutments and parapets
	• culverts
	• overhead sign supports
	• embankments
	  • mainline
	  • ramps
	• electronic toll sites

Barrier-end treatment and transitions	• overall assessment
Surface drainage	• overall assessment
Crossing roads	• horizontal alignment • profiles
Intersections at grade	• intersection sight distance on cross road

5.3.1.2 Mainline design speed
The mainline design speed was set at 120 km/h.

5.3.1.3 Width/staging
Complies with the standards at the time of design.

5.3.1.4 Illumination
See comments under item 5.3.8 (Illumination levels).

5.3.1.5 Bridge piers
See comments under item 5.3.9.2 (Protection of bridge piers).

5.3.1.6 Sign supports
See comments under Section 5.3.9.4 (Overhead sign supports).

5.3.2 Alignment

5.3.2.1 Mainline radius/superelevation
Complies with the standards at the time of design.

5.3.2.2 Ramp geometrics

5.3.2.2.1 Entrances (400 series interchanges)
See comments under Section 6.6.

5.3.2.2.2 Entrances (other interchanges)
See comments under Section 6.6.

5.3.2.2.3 Exits (400 series interchanges)
See comments under Section 6.6.

5.3.2.2.4 Exits (other interchanges)
Complies with the standards at the time of design.

5.3.2.3 Horizontal sight distance

5.3.2.3.1 Bridge abutments
Complies with the standards at the time of design.

5.3.2.3.2 Bridge parapets
Complies with the standards at the time of design.

5.3.3 Profiles

5.3.3.1 Stopping sight distance
Stopping sight distance on ramp Highway 27N to Highway 407 W is substandard and is therefore a minor safety concern. There is no apparent reason for this. Otherwise, stopping sight distance generally meets MTO standards; however, in most cases crest curves are minimum values.

5.3.3.2 Sight distance to bullnose
In three cases, sight distance to the bullnose does not meet the MTO standard. The standard gives a range of distances in which the lower end is 370m. At the Bramalea Road exit westbound, the sight distance is approximately 160m. At the Yonge Street exit eastbound, there is a crest curve on Highway 407 that limits the sight distance to approximately 290m. At Pine Valley Road eastbound on Highway 407, there is a crest curve that limits the sight distance to approximately 195m. These substandard sight distances are a concern; the committee recommends that these conditions be reviewed.

5.3.4 Typical mainline cross-sections (see Figure 5.4)

5.3.4.1 Lane widths
Complies with the standards at the time of design.

5.3.4.2 Shoulder widths
Complies with the standards at the time of design.

5.3.4.3 Superelevation
Complies with the standards at the time of design.

5.3.4.4 Crown location
Complies with the standards at the time of design.

5.3.5 Speed-change lanes

5.3.5.1 Exit terminals
Some exit terminals are mildly non-compliant.

5.3.5.2 Entrance terminals
Do not meet current standards; refer to Section 6.7.

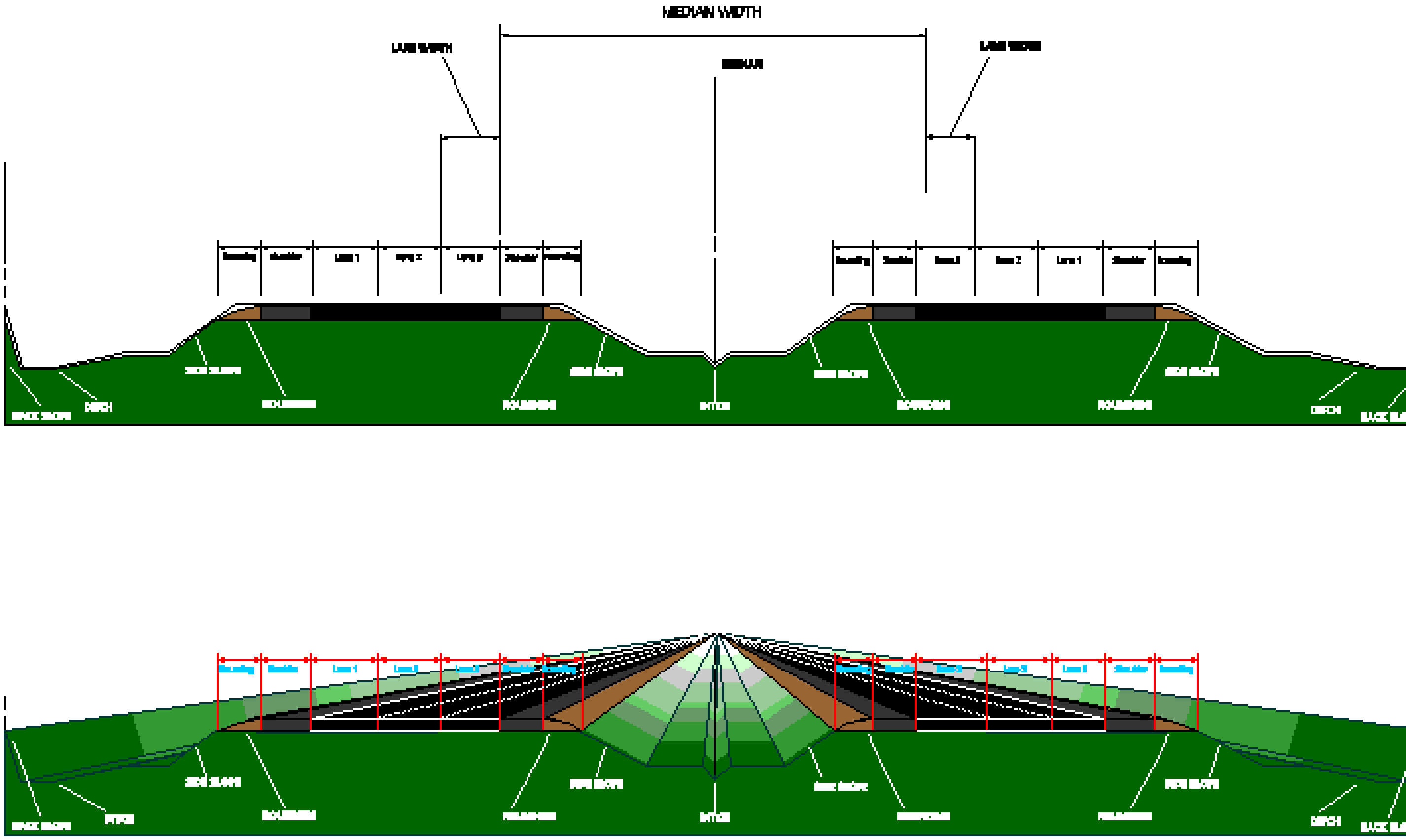


Fig 5.4. Typical Cross-Section Basic Six-lane Configuration

5.3.6 Lane balance

5.3.6.1 Exit terminals
Complies with the standards at the time of design.

5.3.6.2 Entrance terminals
Complies with the standards at the time of design.

5.3.6.3 Basic lanes
Complies with the standards at the time of design.

5.3.6.4 Lane continuity
Complies with the standards at the time of design.

5.3.7 Signing and marking Signing plans were not available. Limited marking plans were available for some sections of the main roadway and interchanges, and the design appears to be satisfactory. Refer to Section 6.10.

5.3.8 Illumination levels Average illumination was calculated at representative sites along the mainline and across the entire cross-section of the highway, including shoulders. Calculations were not made for directional interchanges, because of their geometric complexity. Based on MTO criteria, all selected mainline sections of the highway were found to be compliant.

5.3.9 Protection for safety

5.3.9.1 Lighting poles
See Sections 6.3, 6.4, 6.5.

5.3.9.2 Bridge piers, abutments and parapets
Some barrier protection lengths fail to meet MTO standards. This is a concern to the committee and merits further review.

5.3.9.3 Culverts
A number of culverts on side slopes have not been tapered to match the slope. It appears that the deficiency list prepared by the independent agent in the course of commissioning the highway has also noted these locations. As a result, we expect such culvert modifications as required will be made.

5.3.9.4 Overhead sign supports
Some barrier protection lengths fail to meet MTO standards. This is a concern to the committee and merits further review.

5.3.9.5 Embankments
See comments in Sections 6.4, 6.5, 6.8.

5.3.9.5.1 Mainline
Some barrier protection lengths fail to meet MTO standards. This is a concern to the committee and merits further review.

5.3.9.5.2 Ramps
Some barrier protection lengths fail to meet MTO standards. This is a concern to the committee and merits further review.

5.3.9.6 Electronic toll sites
Some barrier protection lengths fail to meet MTO standards. This is a concern to the committee and merits further review.

5.3.10 Barrier-end treatment and transitions Complies with the standards at the time of design.

5.3.11 Mainline surface drainage The MTO desirable minimum grade is 0.5% and the absolute minimum grade is 0.3%. Some grades are less than 0.3%. This is not a concern, provided that the roadway is not curbed and that lateral drainage is maintained in accordance with prevailing standards.

5.3.12 Crossing roads

5.3.12.1 Horizontal alignment
Complies with the standards at the time of design. *5.3.12.2 Profiles*
Complies with the standards at the time of design.

5.3.13 Intersections at grade

5.3.13.1 Stopping sight distance on cross roads
Complies with the standards at the time of design.

5.4 Statement of conformity to standards

It is our view that in general - and with the exception of the specific instances discussed and referred to above - Highway 407 was designed in accordance with the prevailing standards as set out by the Ministry of Transportation of Ontario at the time the project was undertaken.

6. ISSUES ARISING

6.1 Introduction In the preamble to this report and in Chapters 3 and 4, we tried to stress the importance of considering road safety explicitly during the road design process. Adherence to standards does not guarantee a sufficiently safe design. Non-compliance does not necessarily mean that a road is not sufficiently safe. Circumstances present themselves for which there is no ready-made answer. In such situations, careful analysis and research can prove to be a designer's greatest ally.

The Highway 407 project has been subject to intense media and public scrutiny over the past few months. In the course of the public discussion, a number of issues have been raised by various stakeholders. The committee felt strongly that these, and a collection of related issues, had to be addressed specifically in this report. That is one primary purpose of this chapter. The second is to answer the four fundamental questions (see Section 3.9) which underlie our mandate:

- ***Question 1.*** *Does Highway 407, as built, meet or exceed the prevailing Ontario design standards that have a bearing on road safety?*
- ***Question 2.*** *Were the standards used and the design decisions made in a manner that appropriately addresses safety?*
- ***Question 3.*** *Were cost-effective opportunities to enhance the safety of Highway 407 examined and exploited during its design?*
- ***Question 4.*** *What seemingly cost-effective opportunities to enhance the safety of Highway 407 exist now?*

The remainder of this chapter focuses on nine issues. In each, we first present an overview of the topic. Then, where applicable, we attempt to answer the four questions for that issue. Where possible, initial recommendations for action are also provided.

6.2 Median width

Two of the central concerns expressed about Highway 407 are the unprotected lighting masts in the median and the absence of a median barrier to prevent cross-median collisions. Both concerns are tied to the width of the median. The wider the median, the fewer vehicles would encroach far enough to collide with the masts or cross over into the opposing traffic stream. This section will begin by a discussion of the technical background, history of the median width for Highway 407, and how the median width has been shaped by the value engineering exercise.

6.2.1 Overview

6.2.1.1 Background

"A median is the area that laterally separates traffic lanes carrying traffic in opposite directions... .The terms wide and narrow are often used to distinguish different types of median." (Ref. 1, D 1-1).

The Ontario standards state: "Medians should be as wide as possible", but also recognize that the choice must be affected by economic considerations. The wider the median, the more land will be needed, the more area will be graded, the longer will be the bridges crossing the road, and the costlier will be some hydraulic structures for streams and drainage. Accordingly, *"Median widths may be as narrow as 1m and as wide as 30m" (Ref. 1, D 6-1). The standards also say: "A median width between 10m and 15m, with 10:1 slopes[1] does not usually require a barrier..."* (Ref. 1, D 6-1).

Ontario standards say very little about the road safety consequences of selecting various median widths. The corresponding document prepared by the Transportation Association of Canada is a bit more explicit. It says: "*... one aim in median design is to minimize the chance of cross-median accidents and the severity of accidents resulting from vehicle encroachment... . Accident experience has shown that wider medians are generally safer... . Medians 30.0m wide are now accepted standards in some areas...". (Ref. 2) The more recent (1986) edition of the same document says: "Wide medians promote safety by reducing the possibility of collision by vehicles travelling in opposite directions."* (Ref. 3, C-24).

A recent review of the literature[2] states:

"There have been a substantial number of highway safety research studies that have attempted to investigate median widths, median barriers and median cross-slopes. In general they have found median width to be directly related to total accident rate." That is the wider the median, the fewer are median collisions in general, not only cross-median collisions. These studies include the work by Garner and Dean (Ref. 4, 1973), using data from Kentucky, Seamons and Smith (Ref. 5, 1991), using California data, and Knuiman et al. (Ref. 6, 1993), using data from Utah and Illinois. Our examination of the California data indicates that the number of cross-median collisions:

- increases approximately in proportion to the average daily traffic; and
- diminishes with median width.

For example, using the California data,with a 15m median and 120,000 vehicles each day, one may expect about 0.3 cross-median collisions/km/year, whereas with a 30m median, there would be only 0.06 cross-median collisions/km/year. (Ref. 5, 1991)

The committee found only one MTO report peripherally addressing the issue of median width on a part of Highway 401[3]**.** On that section of Highway 401 with a 15.2m-wide median, 9% of the collisions (129 of 1436) were of the cross-median type. On that section of Highway 401 with a 7.6m median, 13.6% (342 of 2522) were cross-median collisions[4].

The selection of the median width for Highway 407 went through several transformations. As one of the value engineering reports explains: *"Originally Highway 407 was designed for eight ultimate basic lanes with a 15m median, with open ditches. Subsequently it was decided to allow for 10 ultimate basic lanes with an urban median using the same grading width." (Ref. 8, Technical Paper No. 2.17). This apparently refers to the decision by the MTO Management Review Committee of July 21, 1987 to adopt "protection for an ultimate 10 lanes on Highway 407 with a **7.5m urban median with barrier.**"* (Ref. 8, Technical Paper 2.16, p.1). Later, in May 1991, MTO noted that a 7.5m median probably could not accommodate wide bridge piers and still leave a 3.0m minimum shoulder width. Therefore, the decision was to increase the minimum median width from 7.5m to **8.5m**.

In this early part of the Highway 407 history, safety considerations played a role in the decision to widen the median from 7.5m to 8.5m. The committee has no documents to tell what role safety considerations played in the earlier MTO decision to have a 15m median, or in the later MTO decision to shrink it to 7.5m. Within a right-of-way such as that of Highway 407, there is usually room for a wide median. Once the land for the right-of-way has been acquired, its cost is no longer relevant for the decision about median width. The trade-off is now between the safety benefits of a wider median and the cost of longer structures and more grading. The committee has no documents to determine whether this balancing was done by the MTO.

6.2.1.2 Median width in the value engineering phase

The safety of Highway 407 as it now exists has been determined by decisions made over a long period. Many important decisions were made and facts established before 1993. These decisions were made by the MTO. In 1993, two consortia were invited to engage in the value engineering phase. Suggestions for modifying the MTO design were made by both consortia. The two consortia started from different premises. Ontario Road Development Corporation (ORDC) seems to have assumed that MTO had called for a median that for most of the road was 15m wide. CHIC assumed that MTO had called for an 8.5m median.

The MTO terms of reference for the value engineering state: *"The objective of the value engineering assignment is to review the plans for Hwy. 407 and determine if more cost-effective designs for the facility can be developed."* (Ref. 7, Appendix 1 to Approved Work Plan). The same document explicitly states that: *"Alternative designs should not impact on the level of safety of the facility, otherwise all other options will be considered by the ministry.""The only criteria which in our view are mandatory and not subject to change are lane widths and vertical clearances."* (Ref. 7, Activity 3, letter by D. P. Garner, June 28, 1993).

6.2.1.2.1 Median width in the ORDC value engineering

The ORDC consortium did not build the highway. Still, the examination of its value engineering document is of interest inasmuch as it has influenced the terms of reference that were formulated using the results of the value engineering phase, and therefore the highway as it now exists.

In defining their cost savings estimating procedures, the ORDC consultants state: *"A review of the various MTO standards, specifications and procedures will be made to identify changes that will result in cost savings while still maintaining the safety and appropriate level of service of the project."* The promise was that the proposed changes would not adversely affect safety and the proposed cost savings would maintain the safety of the MTO designs.

The ORDC value engineering document discusses median width under Activity 11 (Ref. 7, Typical Cross-Section Elements). It is stated that the current design criteria call for a 15m median west of Woodbine Avenue and an 8.5m median east from there once the "ultimate" cross-section is eight lanes. The ORDC team suggests using *"an 8.5m median throughout ... "*. This is estimated to save about $150,000/km in grading and $250,000/km in structures and culverts, amounting to a total cost saving of $400,000/km. Eventually, when all lanes were built, the reduced median width would require a median barrier, at a cost of $400,000/km, whereas the 15m median was deemed not to require a barrier. Since this expense would be incurred in about the year 2011, only the present value of $400,000/km would have to be subtracted from the anticipated cost savings. If the present value of $400,000 spent in 2011 is about $180,000, the reduction of the median from 15m to 8.5m represents a savings of about $220,000/km.

The essence of the ORDC proposal was to reduce the cross-section by 6.5m. Thus, at each stage of highway development, the median would be 6.5m narrower than had been originally proposed by the MTO. With eight lanes, it would be 8.5m instead of 15m; with six lanes, it would be 16m instead of 22.5m; with four lanes, it would be 23.5m instead of 30m.

No mention is made of the impact of the proposed median reduction on safety. The implication is that reducing the median by 6.5m would not have increased the number or severity of cross-median collisions before the year 2011 (when a median barrier was assumed to be built). This is at odds with what has been explicitly written into the Canadian standards (Ref. 2), and is contrary to findings of research.

The additional implication is that after the year 2011, it would be just as safe to have an 8.5m median with a barrier as to have a 15m median without a barriWhen r. This, too, is at odds with what is known and done. The warrants that identify potential needs for additions to the highway maintain that for a 15m median a barrier is usually not required. This means that those who formulated these warrants believe that it is usually safer to have a 15m-wide median without a barrier than to have a 15m median with one. The wider the median, the safer it is. Therefore, a 15m median without a barrier should have been thought safer than a 15m median with a barrier, which, in turn, should have been thought safer than an 8.5m median with a barrier.

The change proposed by ORDC was estimated to save a total of about $220,000/km, but would have caused somewhat more collisions in perpetuity. There is no evidence that an attempt was made to estimate how many more collisions would occur because of the change, or whether the savings would be justified in light of these added collisions.

6.2.1.2.2 Median width in the CHIC value engineering Building on the decisions made by MTO earlier, the suggestions by CHIC to reduce median width and the decision by MTO to adopt this suggestion influenced the safety of the road as it now exists.

The starting point for value engineering by CHIC was the MTO proposal to have, at the ultimate stage of development, an 8.5m-wide median (Ref. 8, Technical Paper 2.26, p.1). The task was to identify opportunities for cost savings. The essence of the CHIC proposal about median width was to provide a 7.5m-wide median throughout, with local widening near the bridge piers, and smooth transitions between the two widths.

On the issue of how the illumination masts in the median would be accommodated, two "requirements" were examined. First, in the ultimate stage, when the lighting masts would be incorporated in the median barrier, it would have to be locally widened (from 0.80m to 1.745m). This would amount to a local narrowing of the shoulder. A 3m shoulder was thought to be required. The wider barrier near the masts would make the shoulder slightly less than 3m wide at pavement level. But because the barrier was wider at the bottom than at the top, at bumper height the horizontal distance between the barrier and edge of the travelled way was 3.06m. In this way, the "requirement" was thought to be met.

The second requirement was that in the initial stage the masts be far enough from the travelled lane so that "*it would not be necessary to install a continuous median barrier to meet the current safety criteria during this stage."* (Ref. 8, Technical Paper 2.16, p.2). This requirement was met, too: The distance to the mast would be 10.13m.

Having satisfied the "requirements" the authors conclude: *"The 7.5m median, with transitions where required, caters for an equivalent level of safety by providing the required 3.0m minimum shoulder width."* (Ref. 8, Technical Paper 2.16, p.3)

The net effect of the recommendation was to have a median narrower by 1m at all stages of the life of Highway 407. This was a marginal change. But then, the savings were marginal too_$44,000/km. Reducing the distance from the edge of the road to the masts, to the opposing traffic, or to the median barrier will have the effect of increasing the frequency of collisions. There is no evidence in the value engineering report that this detriment to safety was considered.

6.2.2 Comments and questions

Having reviewed the relevant standards on what is known about the relationship between median width and safety, and some aspects of the process that led to choice of median width, several comments are in order. They are offered under the headings: Were standards met? How was safety addressed in the design process? Were cost-effective opportunities to improve safety taken? Are cost-effective opportunities to enhance safety available?

- *Were prevailing standards met with respect to median width?*

The pertinent standards here are those of median width, which in the ultimate stage should be 7.5m (Ref. 1, D6.2.2), the shoulder width, which is normally 3.0m (Ref. 1, D5.3), and the 10m distance to obstacles that do not require a barrier. All these standards were met.

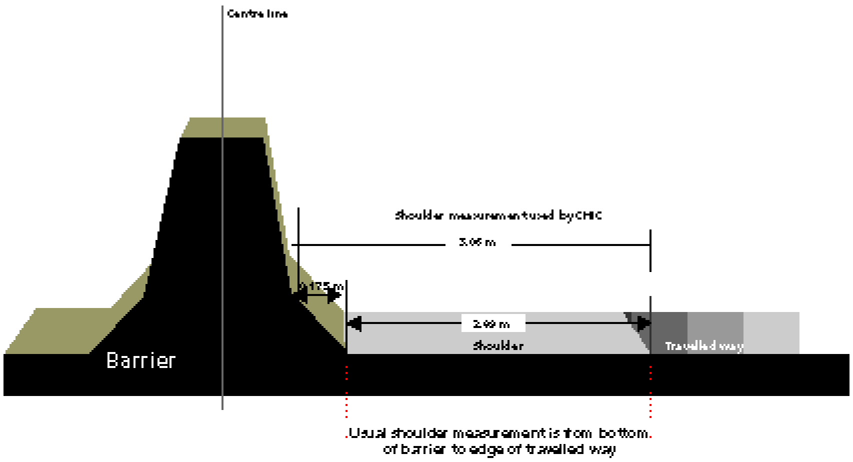


Figure 6.1. Median shoulder measurement on Highway 407

To meet the shoulder-width standard, interpretation of what is meant by "shoulder" was required. The dimension of a shoulder in engineering drawings is generally the horizontal distance from the edge of the travelled lane to the bottom of the barrier. Here, it is redefined to be the horizontal distance to some point on the tapered portion of the barrier (see Figure 6.1). This redefinition enabled the 3.0m width standard to be met. This illustrates how a design process can be distorted to meet minimum standards. The committee does not condone this practice. However, the committee does not think that a few centimetres shortfall in shoulder width makes much of a difference to safety.

- *How was safety addressed in the design process with respect to median width?*

The main decisions about median width were made by MTO several years ago. The committee had no documentation about how these decisions were made.

The consortia examined the cost savings that could be obtained, starting with the MTO design as the base. There is no evidence that in their value engineering work the consortia took into account the known fact that wider medians are generally safer.

Both consortia seem to have resolved the challenge of proposing cost-cutting opportunities that would not adversely impact safety by analyzing whether the proposed design change met the standards instead of whether the proposed change would increase collision frequency or severity. This implies a notion of safety that is unrelated to collision frequency or severity. A notion of safety that allows one to claim that the level of safety has been maintained even if accident frequency or severity are likely to increase is inconsistent with the public good.

It must be emphasized here, as we do elsewhere in this report, that accepting the minimum standard as the demarcation between "safe" and "unsafe" was and is normal practice. One should therefore not be unduly critical of the two consortia. Our purpose here is to criticize an artificial notion of safety that allows one to cut costs without considering the attendant effects on safety.

MTO examined both value engineering reports and asked one of the two consortia to build the road. MTO was also advised that:

"Savings from reduced design standards should be identified separately to see that the reduced safety provision, which is inevitably the case at every compromise with the design standards is worth the savings." (Ref. 9, p.2-2).

By accepting the value engineering reports, MTO appeared to agree that its condition that *"Alternative designs should not impact on the level of safety of the facility"* had not been violated by reducing the median width. It is this condition when coupled with the need to reduce cost that the committee believes is the root of the subsequent distortion in the design process.

It is simply untrue that a road built to standards is as safe as it can be. With more money it can be made safer. The consequence is that someone must decide what the appropriate balance is between the expenditure of public money and the purchase of public safety. The government did not make this difficult decision, thereby placing the two consortia in the situation of having to find substantive cost savings while maintaining safety. To do so, those who wrote the value-engineering reports argued that if the standard was still met after the change, the design was safe - even when the proposed change would normally be expected to increase accident frequency or severity. The expected safety consequences of the proposed changes to the MTO design were not quantified, nor were they subjected to a cost/benefit analysis. As a result, the expected safety consequences of the cost-cutting suggestions did not play an appropriate role in the process by which the highway evolved.

- *Were cost-effective opportunities to enhance the safety of Highway 407 examined and exploited with respect to median width?*

The formative decisions about median width were made by MTO early in the process, but we do not know how. It is possible only to surmise that the starting point in the decision making was the 7.5m width of the "ultimate stage" in Figure D6-2 of Reference 1. From there, one needs only to add the appropriate lane widths to arrive at the approximate width of the median during stages preceding the ultimate stage (7.5 + 2 x 3.50 = 14.5m; 14.5 + 2 x 3.75 = 22m). The same standard explicitly states that median width in the early stage can be in the 22.0 to 30.0m range. However, the opportunity to have a wider median has not been taken.

As noted earlier, the 7.5m median would have made it difficult to maintain 3.0m shoulders near bridge piers. For this reason, MTO later opted for an 8.5m median. This decision was subsequently reversed to reduce cost.

In theory, the two consortia could have considered a wider median for that part of the highway on which the bridge structures were not yet built. There is no evidence that they did so. However, since a wider median would have increased the cost to build the highway, they would not normally have entertained such a possibility when the aim was to show cost savings.

Building a wider median would not necessarily have proved cost effective. However, the committee has found no evidence that the question was asked or answered. If one does not ask whether safety can be cost-effectively enhanced, opportunities to do so cannot be taken.

- *What seemingly cost-effective opportunities to enhance the safety of Highway 407 with respect to median width exist now?*

The width of the median is now set. One can attempt to diminish the future frequency and severity of median collisions by several means: protection of the masts, reshaping of the existing cross-section to be more forgiving, safety attention to the hydraulic structures in the median and installation of shoulder rumble strips (see Figure 6.2).

6.2.3 Recommendations

- *What should be examined?*

The committee did not have the time to identify what all the promising courses of action are and to analyze which of those, if any, are cost-effective. We recommend that, among other possible ways to reduce the future frequency and severity of median accidents, the following options be considered:

1. Examine the potential of installing some type of inertial device (barrier) around each mast.
2. Examine the potential of reshaping the median, and in particular the V- ditch in its middle.
3. Examine the potential of shoulder rumble strips.
4. Examine the potential for improving the safety aspects of the hydraulic structures in the median.

- *Considerations for the future*

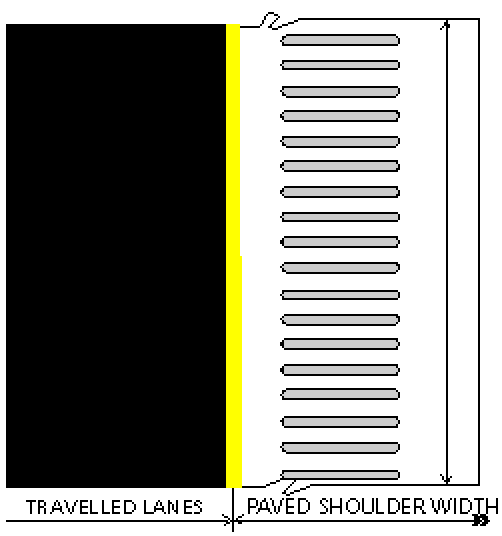


Figure 6.2. Shoulder rumble strips

The committee believes that in future projects, the artificial requirement that cost savings be achieved without impact on an unspecified level of safety should not be imposed. Rather, one should attempt to quantify the impact on safety in the same manner as other impacts are quantified and to justify the proposed cost savings in the usual manner.

The committee finds it disconcerting that decisions affecting the future safety of roads are so strongly influenced by the habit of designing to standards. This often means that minimum standards are just met. There is no reason to think that by meeting standards the appropriate level of safety is built into roads. The guardians of public safety and the engineering profession should address the question of how to build an appropriate level of safety into roads.

6.2.4 References

1. Ministry of Transportation of Ontario. *Geometric Design Standards for Ontario Highways*, Downsview: Surveys and Design Office, 1985.
2. Transportation Association of Canada. *Geometric Design Standards for Canadian Roads and Streets*, Metric Edition, 1976.
3. Transportation Association of Canada. *Geometric Design Standards for Canadian Roads and Streets*, 1986.
4. Garner, G.R. and R.C. Deen. *Elements of Median Design in Relation to Accident Occurrence*, paper presented at the TRB Meeting, January 1973.
5. Seamons, L.L., and R.N. Smith. *Past and Current Median Barrier Practice in California*, Report No. CALTRANS-TE-90-2, 1991.
6. Knuiman, M.W., Council, F. M., and D.W. Reinfurt. "The Association of Median Width and Highway Accident Rate", *Transportation Research Record* 1401, 1993.
7. Ontario Road Development Corporation, *Value Engineering*. Prepared by Marshall Macklin Monaghan; Morrison Hershfield; Delcan Corporation; and McCormick Rankin, Toronto, Ontario, August 1993.
8. Canadian Highways International Corporation, *Phase One, Part I-Value Engineering*. August 1993.
9. FENCO MacLAREN, *Review-Highway 407 Value Engineering*, August 1993.

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1. 1m of descent for every 10m in the horizontal direction.
2. Done in preparation for a research proposal for project 17-14 of the National Cooperative Highway Research Program dated October 1996. (BMI*HSRC)
3. Highway 401, Woodstock to Kitchener, MTO Southwest Region, April 1993.
4. One could extrapolate this to mean that if the median were 15.2m wide where it is now 7.6m, there would have been only 239 cross-median collisions, not 342.

6.3 High-mast lighting

The presence of unprotected high-mast lighting in the median was one of the main safety concerns mentioned in the media. Sections 6.3.1, 6.3.2 and 6.3.3 examine relevant road-safety aspects of the main options that were considered, and describes how the decision to locate the masts in the median was made. Because the question of how far vehicles stray from the road played a central role in this decision, this section also briefly discusses what is known on the matter. On the basis of this discussion, Section 6.3.4 comments on whether standards were met, how safety was addressed in the design process, whether cost-effective opportunities to improve safety were taken, and whether cost-effective opportunities to enhance safety exist now. Section 6.3.5 makes two recommendations.

6.3.1 Overview: the road safety angle

Road lighting is generally thought to reduce nighttime collisions by about 25%. At the same time, illumination poles or masts on the roadside, or in the median, that are within the reach of stray vehicles, are targets for collisions. This partly offsets the safety benefit of illumination.

Some 30%-40% of all fatalities occur in single-vehicle collisions involving a vehicle that left the road. Many of these are collisions with such fixed objects as trees, utility poles, culverts, etc. The farther a fixed object is from the travelled way, the less is the chance that a stray vehicle will co llide with it. The faster a stray vehicle travels, the farther it encroaches into the roadside or the median. If the median or the roadside slope down, the encroachment distance increases. Conversely, an up-slope diminishes the encroachment distance.

If a fixed obstacle is too close to the edge of the travelled way, or if beyond the shoulder there is a steep and deep embankment, it is customary to provide a roadside barrier. A roadside barrier is also a fixed object and is the target of collision for stray vehicles[1]. Because barriers are closer to the edge of the travelled way than the fixed objects they shield, and are longer than the fixed objects, collisions with barriers are more frequent than are collisions with unshielded fixed objects. This is why barriers are to be used only if *"striking a fixed object or terrain feature... is considered more objectionable than [striking] the barrier itself"*. (Ref. 3, p.5-1)

Those making design decisions for Highway 407 had the option of placing the illumination masts either on the roadside beyond the right shoulder, or in the median. These two options will be called the "shoulder-location" and the "median-location" options. While two variants of the median-location option were considered, eventually masts were placed in the centre of the median.

The median is now 22.5m wide. As traffic grows, lanes will be added, and the median width will diminish. Adding one lane in each direction (Stage 2) will reduce the median to 15m; adding another lane (Stage 3) will result in a 7.5m median. Thus, initially, the centre of the masts are 11.25m from the edge of the travelled lane. This distance will diminish to 7.5m in Stage 2, and to 3.25m in Stage 3. It has been envisioned that in Stage 2, a continuous steel median barrier on the median side of each roadway would be used to shield the masts. In Stage 3, the steel barriers would be removed and replaced by a concrete median barrier incorporating the masts.

There are several differences between the median-location and the shoulder-location that have a bearing on road safety:

- With the median-location, the distance between the centre of the mast and the edge of the lane is determined by the width of the median; it is 11.25m in Stage 1, 7.5m in Stage 2 and 3.25m in Stage 3. With the shoulder-location, the designer is free to determine how far from the road to place the masts. They could have been placed farther than 11.25m from the road, which would have meant that this distance would have remained unchanged during the life of the road. In particular, the masts could have been placed 15m from the edge of the nearest travelled way as is recommended in the MTO Policy for High Mast Lighting. (Ref. 4)
- With the median-location, during Stage 1, the masts are not shielded; there is a downslope from the edge of the travelled lane toward the masts, and a ditch that may direct stray vehicles toward the masts. With the shoulder-location, some masts would have been located behind a roadside barrier wherever there was one, and some masts would have been placed on the back slope behind the drainage ditch. Only masts on fill slopes and level areas would effectively be the target of stray vehicles.
- Beginning with Stage 2, when two, continuous, steel median barriers are scheduled to be used to shield the masts in the median, collisions with the barriers would have to be taken into account. However, there would also be safety benefits, because of the reduction of cross-median crashes.
- Beginning with Stage 3, when the median is scheduled to be only 7.5m, a concrete median barrier would be built to reduce the number of cross-median crashes. Because the masts would be moved to a new foundation within the new median barrier, the presence of the masts in the median barrier would become immaterial. However, this should not be taken to mean that vehicles would not collide with the concrete median barrier. On the contrary, the new concrete median barrier would be a major hazard; only the masts themselves would cease to be a hazard. In comparison, if the shoulder-location were chosen, those masts not shielded by a roadside barrier or placed on the back slope would continue to be the target of collisions after Stage 3 was built.

- Because of illumination-engineering considerations, the number of masts required for the shoulder-location option would be somewhat larger than for the median-location option, meaning that the shoulder-location would present more collision targets for stray vehicles. On the other hand, the number of collisions with obstacles is thought to be proportional to the amount of traffic. Because a mast in the median is a target for traffic from both directions, while a mast on the shoulder is a target for traffic from only one direction, unless the shoulder-location option required more than double the masts for the median-location, under equal conditions of distance and topography, the shoulder-location could be expected to have fewer collisions with masts.
- Another consideration is the likelihood of vehicles to stray to the left (on the median side) or to the right. Based on a collision analysis of the MTO Central Region, of a total of 13,474 freeway collisions, 2420 were in the left shoulder and 1588 on the right shoulder.

Whether the shoulder-location would have been safer in the long run is difficult to say without a detailed analysis. To do such an analysis one would have to specify when Stages 2 and 3 are to be built, how many masts would be needed for the shoulder-location, and how far from the edge of the travelled way they would be placed. For the discussion here, it suffices to say that the two options are likely to be different in their safety repercussions. Without the benefit of a detailed analysis, the committee is of a belief that the aforementioned considerations indicate that the shoulder-location might be safer during Stages 1 and 2.

6.3.2 Evolution of the design concept

Originally, the masts were to be along both shoulders in a staggered pattern[2]**.** However, during the detailed design of one project[3] it turned out that the cost of the shoulder-location was substantially higher than originally estimated. *"In view of this, it was decided by senior management to commission a study to analyze all cost and safety aspects of centre median vs. shoulder located High Mast Lighting systems ... "*. (Ref. 1, p. 4)

The commissioned study concluded: *"The proposed staging where the Highway is to be widened on the median side does favor a shoulder mounted system."* (Ref. 1, p. 101) Even though the initial capital outlay for the shoulder-located system was found to be higher than that of the centre-median system, the latter would have to be protected by a steel guiderail when, at a later stage, additional lanes were to be built. This, and the cost of collisions with the guiderail turned the economics in favour of the shoulder-location option. As a result, the study recommended that shoulder-located masts be used, except for the stretch between Jane Street and Highway 404, where shoulder-located masts might interfere with the Dunlap Observatory. (Ref. 1, p.101)

A few months later, another report (Ref. 2) was tabled. Its main subject was an examination of criteria for glare control. As a result of this study, *"the Ministry's Management decided (March 17, 1992) to introduce a lighting system rating based on High Mast Glare Mark (HG) concept, as an additional design requirement."* (Ref. 2, p. 16) To comply with this requirement, the original spacing of masts, when located on the shoulder, had to be reduced. This meant more masts, and further increased the initial capital outlay for the shoulder-location option. A new economic analysis was conducted and is included in the same report (Ref. 2). Unlike the analysis in Reference 1, the new economic analysis did not consider what will happen in Stages 2 and 3. The assumption was that "the second and third stage of the construction will occur in the distant future (15-20 years) ...".[4] With this as the working assumption, there would be no need to add a steel guiderail in Stage 2, or to remove it in Stage 3 to be replaced by a concrete median barrier.

Both economic analyses (Ref. 1, 2) assume that fixed objects farther than 10m from the edge of a travelled lane are never hit.[5] This assumption is incorrect. For more detail, see Section 6.4.1.4. With this, and the assumption that only Stage 1 needs to be considered, the economic analysis in Reference 2 could disregard all safety costs, because in the shoulder-located option and also in the median-located option, the masts would be placed more than 10m from the edge of the lane. Accordingly, collision costs did not feature in the life-cycle cost of the economic analysis of either option in Reference 2. The comparison of the shoulder-located vs. median-located masts (with the "glare requirements") in Reference 2 was confined entirely to the cost of construction, operation and maintenance. Neither the cost of collisions, nor the future costs of building steel guiderails and, later, a concrete median barrier, feature in the final economic comparison of these two options. The median-located option carried the day.

Although in Reference 2 the cost of crashes with masts was dealt out of the economic comparison between the median-location and the shoulder-location, such costs did feature in the earlier report (Ref. 1). In addition, Minutes of meetings indicate concern by MTO engineers. (On June 10, 1991 the Minutes mention several engineers who preferred the shoulder location. On May 3, 1991, the view was expressed that the analysis must include collision costs. In October 1990, the view was expressed that a catastrophic event [presumably a truck knocking over a mast] should be considered in the life-cycle cost analysis.)

6.3.3 Encroachments: a reality check

The economic analyses in References 1 and 2 are shaped by the following quote:

"Traffic safety considerations are based on the Ministry's directives for high mast lighting. Shoulder mounted poles are located a minimum of 10m from the edge of travelled pavement. Protection is not required for poles located at a distance greater than 10m from the edge of travelled pavement; therefore, incidence costs [presumably collision costs] are not applied for shoulder mounted system." (Ref. 1, p. 7).

Thus, the assumption is that if an object is located more than 10m from the edge of the travelled lane, it is almost never hit. This assumption was also used in the economic analysis of the median-located option in Stage 1 (Ref. 2).

All empirical evidence0 negates the belief that obstacles 10m or more from the edgeline are never collided with. The available data on encroachment have been carefully considered by the Task Force on Roadside Safety, which wrote the most recent *Roadside Design Guide* (Ref. 3). In the best judgment of this task force, when the design speed is 120 km/h, as on Highway 407, and when the terrain beyond the shoulder is level, 20% of the stray vehicles will go farther than 10m from the edge of the travelled lane. If the terrain is sloping down, these percentages will be even larger. The *Ontario Roadside Safety Manual* uses the same information about how far vehicles stray from the road. It makes abundantly clear that many errant vehicles stray farther than 10m from the outer edge of the lane.(Ref. 5)

6.3.4 Comments and questions

Having reviewed some of the relevant factual information, and discussed important aspects of the process that led to the choice of the centre-median location for the masts, several comments are in order.

- *Were prevailing standards met with respect to high-mast lighting?*

Rural freeway medians are usually wide and without full illumination. Urban freeway medians are usually narrow and full illumination is common. It is relatively rare to encounter a freeway that is fully illuminated and is designed to "rural" standards. This makes the combination of a 22.5m median, without a median barrier but with illumination masts in the middle, a somewhat uncommon design. We do not know of a specific standard that pertains to this combination of circumstances. The only applicable standard is that obstacles such as masts, if less than 10m from the edge of a lane, should be protected. Since the distance is now somewhat more than 10m, the letter of this standard has been met.

The *Ontario Roadside Safety Manual* is explicit in stating that where the "design speed" is 120 km/h, the 10m clear roadside is a minimum (Ref. 5, p.0202-4, Table 2.2.1). In addition, the high masts are exceptional obstacles, not only in their rigidity, but also in the consequence to uninvolved parties in the unlikely event that one should be toppled. This is why the MTO Policy for High Mast Lighting (Ref. 4, p.6-20) states: *"Any high mast pole, located outside the travelled lanes, i.e. mainline, deceleration, acceleration or ramps, and not behind a guiderail or barrier will require a minimum of 10m (desirable 15m) offset from the edge of the nearest travelled lane."* Thus, while the minimum standard has been met, the spirit of the standard has not been met.

- *How was safety addressed in the design process with respect to high-mast lighting?*

Earlier, we described our understanding of how the decision to place the masts in the centre of the median had been reached. In the first economic analysis (Ref. 1), an attempt was made to explicitly account for future safety costs. Already in the analysis, it was assumed that objects farther than 10m from the edge of the pavement would never be hit. In the second economic analysis (Ref. 2), which led to the eventual decision, the same assumption was used, making future safety costs immaterial to the decision at hand.

It is one thing to say that masts farther than 10m from the edgeline do not require protection. It is another thing to extrapolate this to mean that such objects are almost never collided with. The former is a matter of deciding whether it is better to leave the mast unprotected or to place a new, but more forgiving, obstacle (a barrier) between the mast and the road user. The latter disregards the available empirical evidence that exists and should be used in engineering practice.

The use of this questionable assumption distorts the economic analysis in uncertain ways. Whether the results of the economic analysis would be reversed if a more informed assumption had been made is not the main point. After all, the masts are now in the median and it would not be sensible to move them. The main point is that the process that led to the decision to place unprotected masts into the median was unsatisfactory.

One may ask: Why were the engineers not informed about the nature of roadside encroachments? What led them to assume that obstacles farther than 10m from the edge of the outer lane are almost never hit? How could they make the leap from the statement that "Protection is not required for poles located at a distance greater than 10m from the edge of travelled pavement" to the notion that the cost of collisions could be disregarded? Why would the ministry accept a report and make its design choice on the basis of economic analyses that base the costs of collisions on an assumption that is contrary to what its own *Roadside Safety Manual* clearly says: 20% of stray vehicles may be expected to encroach farther than 10m?

A partial answer to these questions can perhaps be gleaned from juxtaposing the rigour of road safety engineering generally with that of illumination engineering generally, as illustrated by this specific case. The report on glare control criteria (Ref. 2) sparkles: There are data, computer modelling, accepted guidelines, consultants. On the road safety side, there are only a few letters to various highway departments and reference to a ministry directive. There is no evidence that road-safety expertise was used, no report giving engineering information about the road-safety aspect of the mast, no data, no computer modelling and no explicit analysis. Thus, one part of the answer is in the apparent assumption that road-safety-related decisions can be made without using road-safety-engineering expertise, or by the strict adherence to standards.

Whether the fact that the centre-median location was the least expensive to build played any role in the process we cannot know.

- *Were cost-effective opportunities to enhance the safety of Highway 407 examined and exploited with respect to high-mast lighting?*

The possibility that the shoulder and the median-location options may differ in safety was recognized early. The different safety consequences of the two options also featured (incorrectly) in the first economic analysis (Ref. 1). However, once the assumption had been made that objects farther than 10m from the outer edge of the lane would never be hit, a further concern about safety may have seemed unnecessary.

The committee notes that the terrain around the masts is shaped to allow service. This shaping may also have had a safety motivation. In general, however, we found no evidence showing that thought was given to protection of stray vehicles from impact with the masts. Nor did we find evidence of concern that the median ditch might point stray vehicles in the direction of the masts. It is our view that the shaping of the median and the protection of road users from the masts should have been examined explicitly and expertly.

- *What seemingly cost-effective opportunities to enhance the safety of Highway 407 with respect to the high-mast lighting exist now?*

It is not practical to move the masts. However, one could attempt to diminish the frequency of future collisions with the masts and to alleviate their severity by several means: protection of masts by some inertial device (barrier), reshaping the median cross-section, installing shoulder rumble strips.

6.3.5 Recommendations

- *What should be examined?*

The committee did not have the time to identify what all the promising courses of action are and which, if any, are cost-effective. We recommend that, among other possible ways to reduce the future frequency and severity of accidents, the following options be considered:

1. Examine the potential of installing some type of inertial device (barrier) around each mast.
2. Examine the potential of reshaping the median, in particular the V-ditch in its middle.
3. Examine the potential of shoulder rumble strips.

- *Considerations for the future*

The process that led to the choice of the median-location for the illumination masts was not based on defensible safety analyses. Decisions that are likely to have a substantive impact on the future road safety of a road ought to consider such road-safety repercussions explicitly, using the best knowledge available at the time the decision is made. Those who make such decisions in the future must have the training and the tools for the task.

6.3.6 References

1. Ministry of Transportation of Ontario, *Highway 407 High Mast Lighting System. An Analysis of Centre Median vs Shoulder Located System*. W.P. 89-79-01. June 1991
2. Ministry of Transportation of Ontario, *Luminaire Selection Study for Highway #407 Lighting Based on Glare Control Criteria*. April 1992.
3. American Association of State Highway and Transportation Officials, *Roadside Design Guide*. Washington, D.C., January 1996.
4. Ministry of Transportation of Ontario. *Policy for High Mast Lighting.*
5. Ministry of Transportation of Ontario. *Ontario Roadside Safety Manual*, 1993.

1. Using a collision analysis report by the MTO Central Region, of 35,768 freeway accidents, in 5016 (14%) a barrier was struck, in 1595 (4.5%) a fixed object was struck and in 1288 (3.6%) the vehicle ran off the road without hitting a barrier or an obstacle.
2. "Electrical predesign reports prepared for various sections covering Highway 407 from Airport Road to Highway 404 included recommendations for the location of High Mast poles along both shoulders with a staggered layout. Shoulder located system was recommended due to the fact that all future expansion will be carried out into the median _". (Ref. 1, p. 4)
3. The highway was built in many segments called "projects".
4. " ...life-cycle cost comparison between the following systems: Shoulder mounted system which includes the glare rating requirements (new); Centre mounted system with glare requirements and the assumption that the future construction staging is not taken into consideration _ ."
5. The details of the economic analysis are included in Reference 1 and allow the reader to determine what was taken into account. Not so in Reference 2. Therefore, we cannot be certain whether the cost of collisions with the median-located masts has been disregarded. However, the present value of the life-cycle cost (Ref. 2, Table5-1) for option 6C, and the absence of any reference to crash costs for option 6C are an indication that crash costs were assumed to be zero.

6.4 The clear zone

6.4.1 Overview

Since the late 1960s, highway engineers have designed using the concept of a forgiving roadside. A highway with a forgiving roadside recognizes that drivers do occasionally run off the road and that serious collisions will be reduced if a reasonable recovery zone free of obstacles is provided. If the obstacles cannot be removed from the recovery zone, they need devices to protect vehicles that might collide with them. The clear zone is the minimum recovery area set by highway authorities for engineers to use during design.

The knowledge gained during more than two decades of experience with the forgiving highway concept, and, specifically, the clear zone, now enables engineers to more precisely estimate their safety impact. In particular, engineers can estimate the number of vehicles that may hit fixed objects beyond the edge of the road and the severity of the outcome.

6.4.1.1 Definitions

The roadside recovery zone definitions are graphically shown in Figure 6.3. The recovery zone is the total unobstructed traversable area available along the edge of the road. By convention, it is measured from the edge of the closest travel lane. The recovery zone may have recoverable slopes, non-recoverable slopes and a clear run-out area.

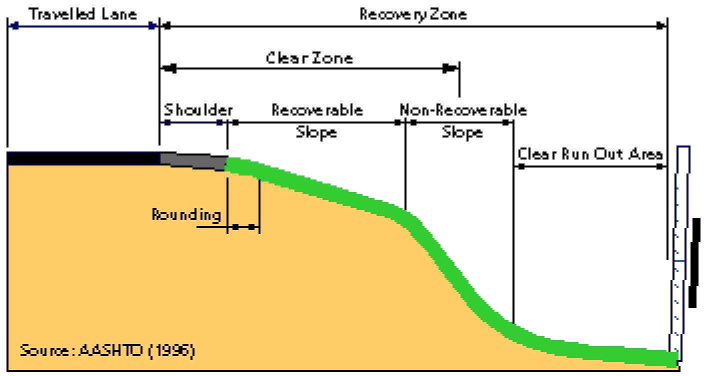


Figure 6.3. Roadside recovery zone (not to scale)

Recoverable slopes are those on which a driver may, to a greater or lesser extent, retain or regain control of a vehicle. A non-recoverable slope may be traversable, but a vehicle will continue to the bottom. A clear run-out area is located at the toe of a non-recoverable slope, and is available for safe use by an errant vehicle. There is also provision for a smooth transition between slopes to allow for the safe passage of vehicles.

The clear zone is the total, fixed-object-free area available to the errant vehicle. The desired clear zone width required by highway design standards has been found to depend on traffic volume and speed, roadway geometry, embankment height, side slope and such environmental conditions as snow, ice, and fog.

The wider the clear zones, the less the frequency and severity of collisions with fixed objects. However, there is a point beyond which any further expenditure to move or protect the fixed objects is not warranted because the marginal risk reduction is too small.

6.4.1.2 Operating experience

Highway agencies have about 25 years' operating experience with clear zones and recovery areas. This experience has improved understanding of the detailed geometric design features of good design. For example, it is known that a 10m clear zone is adequate for a level roadside but needs to be increased in width as the side slope increases to provide the corresponding level of risk. The recoverable zone should be as flat as possible to simplify regaining vehicle control. AASHTO (Ref. 1, p. 3-4 and Figure F-3-5) suggests that a 6:1 slope is desirable. All current definitions treat 4:1 as the steepest recoverable slope and 3:1 as traversable but not recoverable. Any slope steeper than 3:1 is considered a hazard.

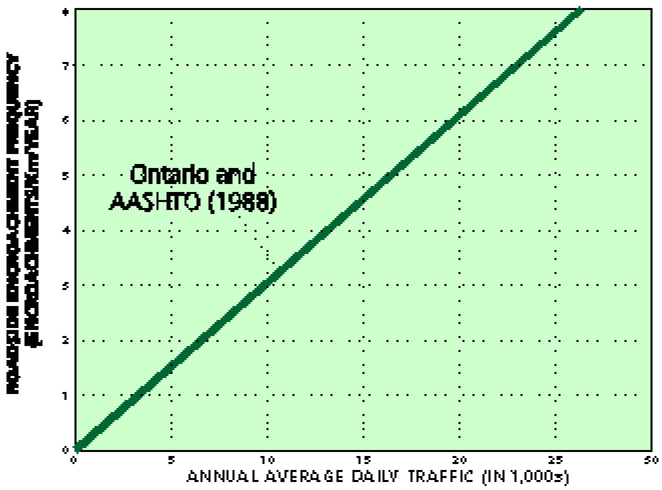


Figure 6.4. Number of expected excursions from high-speed highways

The Ministry of Transportation in its Roadside Safety Manual (Ref. 2) states: *"The design of features adjacent to provincial highways is usually under the direct control of the Ministry of Transportation personnel ..."*. (section 1.2.1) The manual continues: *"The highway designer must therefore ensure the roadside environment is structured to minimize the incidence and severity of accidents"*. These statements are followed by a list of suggested remedial actions by priority, such as removing the hazard, relocating the hazard, and shielding the hazard. The highway designer is instructed *"to deliberately seek opportunities in each project to apply sound safety and traffic engineering principles"* (Ref. 2, Section 1.3). Also: *"The preliminary design report should include safety enhancement opportunities ..."*.

6.4.1.3 Encroachments

Along any highway, a few vehicles are expected to leave the road, because the driver has made an error in judgment or even fallen asleep. The number of expected excursions from high-speed highways is shown in Figure 6.4. The high value is 0.0003 encroachments/km/year/(vehicles/day). The rate applies to each side of the roadway and is measured from the outer edge of the outer lane.

For example, the number of expected excursions from Highway 407, over the length of 36km when the traffic is 25,000 AADT (average annual daily traffic) is about 270 excursions each year to one side of the highway. Both sides in one direction would have 540 encroachments, and for both directions, about 1080 encroachments each year for the entire road.

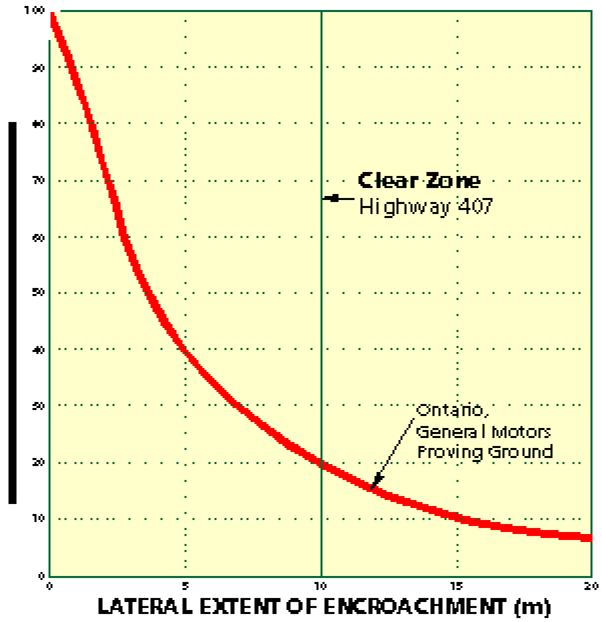


Figure 6.5. Ability of drivers to recover during high-speed vehicle excursions from road

The number of encroachments is increased by such highway characteristics as horizontal curves and downgrades. Other adjustments may be made to account for snow, ice and fog.

6.4.1.4 Encroachment distance

The encroachment distance from the road is measured from the painted lane edgeline. The majority of drivers recover control on the paved shoulder. The ability of drivers to recover during high-speed vehicle excursions from a road is shown in Figure 6.5. The recovery area in these observations is assumed to be level with the shoulder of the road and there is little or no side slope.

The diagram indicates that about 50% of drivers recover on a 3m paved shoulder. The fraction of high-speed excursions beyond 10m, the MTO defined clear zone, is about 20% if the clear zone is flat. This implies that 80% of drivers regained control of their vehicles within 10m.

The ability of a driver to recover control of a vehicle depends in part on the side slope at the edge of the road. For example, the recovery distance for 80% of drivers on a 4:1 side slope is about 14m. The 10m recovery width on a 4:1 side slope allows about 60% of the vehicles to recover, therefore 40% do not recover. (Ref. 1, Figure 3.1, p. 3-3).

6.4.1.5 Severity of impact

The severity of the collision depends on such factors as the angle and speed of impact, the nature of the object hit, the crushing characteristics of the vehicle, and the vehicle occupants' characteristics and if they are wearing a seat-belt.

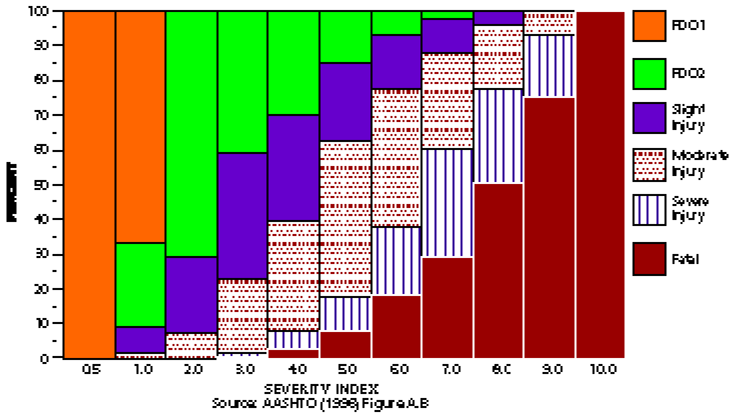


Figure 6.6. Severity index measuring proportions of fatalities, injuries and property damage

Severity is measured by the level of injury to vehicle occupants and damage to the vehicle. The Severity Index (SI) provides engineers with a standard measure of accident severity for comparative purposes. It measures proportions of fatalities, injuries and property damage as shown in Figure 6.6. For example, an SI of 1 has only 10% injury and 90% property damage; an SI of 5 has 8% fatalities, 77% injury and 15% property damage; an SI of 10 has 100% fatalities. Associated with each Severity Index is a cost that reflects the economic evaluation of the road authority.

The severity indexes assigned to various roadside devices, such as bridge piers, were based on the judgment of a committee of engineers. Recent research by Council and Stewart (Ref. 3) has shown those results to be conservative. For example, previously it was assumed that collisions with impact attenuators, such as crash cushions, result in serious injury 3% of the time. In fact, Council and Stewart have shown that serious injury results about 5% of the time. This changes the Severity Index from 4 to 5.

6.4.2 Comments and questions

- *Were prevailing standards met with respect to clear-zone requirements?*

MTO requires clear-zone distance of at least 10m along the mainline for highways with a design speed of 120 km/h and traffic volumes greater than 6000 AADT (Ref. 2, Table 2.2.1 Section 2.2). Recoverable slopes within the clear zone along the high-speed sections should be 4:1 or flatter. CHIC was required to meet the standards of the Roadside Safety Manual (Ref. 2). All the typical cross-sections along the high-speed sections reviewed by the committee generally met these two standards, but failed to follow the MTO directives for flatter slopes. The field investigation found a few median sections where there was little or no rounding at the transition points.

The clear zone on ramps considers the ramp's design speed, traffic and curvature. According to the *Roadside Safety Manual* (p. 0209-7) the ramp's clear zone is to be the same as tangent sections at the same design speed. The slopes at the ramps were generally 3:1, which is considered traversable if free of fixed objects (Ref. 2, p. 0205-2). In the cases reviewed by the committee, the slopes were 3:1 and the clear zones were about 7m and, as such, met the MTO minimum standard.

- *Were cost-effective opportunities to enhance the safety of Highway 407 examined and exploited with respect to the clear zone?*

The typical cross-section for Highway 407 seems to have been set in the preliminary design phase design criteria endorsed June 30, 1983. The ultimate median width of that design is 15m. No obstructions, such as light standards, are indicated in the median. This cross-section came from a meeting held in 1978.

The engineering understanding of the clear zone in 1978 is summarized by a Roads and Transportation Association publication, *Treatment of Roadside Hazards* published in 1979 (Ref. 4). Highways having a design speed of 70 mph (120 km/h) or greater had a clear zone of 9m (Ref. 4, Figure 50, p. 68). The suggested median width was "at least 20m" (Ref. 4, section 9.2.2 p. 50) unless such restrictions as urban conditions or economics precluded such activity. It appears to have been accepted that the 10m distance and 4:1 side slope defined a safe roadside.

The Roadside Safety Manual (Ref. 2) is very specific in dealing with safety conscious design (Section 1.3), stating: *"Designers must deliberately seek opportunities in each project to apply sound safety and traffic engineering principles."* Also: *"The preliminary design report should include all identified safety problems and safety enhancement opportunities."* There is no documentation stating known or suspected safety problems with the strict adherence to the 10m clear zone, except for the centrally located high-mast lighting, which is discussed elsewhere. No documented attempt seems to have been made to go beyond the minimum Ministry of Transportation standards, to enhance safety by a wider or flatter clear zone as suggested in the MTO procedures.

- *What seemingly cost-effective opportunities to enhance the safety of Highway 407 with respect to the clear zone now exist?*

Safety within the available recovery zone may be enhanced by providing protective devices around objects that may be hit and slopes should be flattened where possible. The committee also believes consideration should be given to rounding some of the slope transitions within the recovery area. The drainage and sediment control devices in the median should be tapered and generally made more forgiving.

6.4.3 Recommendations

- *What should be reviewed?*

The committee considers that the following elements in the recovery zone should be reviewed:

1. the rounding at transition slopes within the median;
2. the use of protection, such as energy absorption devices, at the high-mast lights, which although they are outside the clear zone are well within the expected recovery zone for a significant portion of encroaching vehicles;
3. the 3:1 side slopes on some of the ramps, which have fairly high embankment slopes; and
4. some of the drainage and sediment control structures within or near the clear zone, which could be tapered.

- Considerations for the future

Future designs, particularly of high-speed, high-volume highways need to utilize the idea of risk in defining the recovery area and clear-zone. The clear-zone dimension must consider the probability of off-road excursions, severity of outcome and the consequences of side slope, road geometry and environment to enhance traveller safety. Cost-effective safety opportunities need to be examined based on this understanding. Such safety estimates properly go beyond a simple acceptance of minimum geometric design standards as being adequately safe.

6.4.4 References

1. American Association of State Highway and Transportation Officials, *Roadside Design Guide*, Washington, D.C., 1988 and 1996.
2. Ministry of Transportation of Ontario, *Roadside Safety Manual*, Downsview, 1993.
3. Council F., Stewart J., "Severity Indexes for Roadside Objects," *Transportation Research Record* 1528, Washington, D.C.: Transportation Research Board, pp. 87-96.
4. *Treatment of Roadside Hazards*, Roads and Transportation Association of Canada, Ottawa, 1979.
5. Zegeer, C.V., Twomey, J.M., Heckman, M.L. and J.C. Hayward. *Safety Effectiveness of Highway Design Features, Volume 2. Alignment*, Washington, D.C.:FHWA, 14 p., 1992.

6.5 Traffic barriers

6.5.1 Overview: what are traffic barriers?

Traffic barriers are protective devices that are placed between traffic and a potential hazard off the roadway, with the intention of reducing the severity of an accident when an errant vehicle leaves the travelled portion of the roadway. This is accomplished by containing the errant vehicle and deflecting it away from the hazard in a controlled manner with acceptable deceleration, low exit angle, and minimum injury to the occupants or damage to the vehicle, or by gradually decelerating a vehicle to a safe stop.

Traffic barriers do not prevent accidents. After all, they too are obstacles on the roadside and vehicles striking barriers can cause occupant injury and/or vehicle damage. A traffic barrier should be installed only if it is likely to reduce the severity of potential accidents.

The barrier design process consists of first determining the need for a barrier through a warrant analysis, and then selecting an appropriate barrier type on the basis of the level of protection it offers, its deflection or deceleration characteristics, and conditions at the site where it is proposed to be installed.

Two types of traffic barriers are typically encountered on today's highways, longitudinal barriers and energy attenuation devices or crash cushions. Longitudinal barriers function primarily by redirecting errant vehicles, while crash cushions function primarily by absorbing energy and decelerating errant vehicles to a stop for head-on impacts, or by redirecting a vehicle for side impacts. Longitudinal barriers include a barrier within the median of a divided highway and a barrier adjacent to the roadside of a divided or undivided highway.

6.5.1.1 Roadside barriers

Roadside barriers are longitudinal barriers installed adjacent to the right or left edge of a roadway. Their primary purpose is to prevent a vehicle leaving the roadway from striking such fixed obstacles as sign posts or bridge piers, or such terrain features as trees or rock outcrops, or from encountering a steep slope, when these features are considered to be more hazardous than the barrier itself.

6.5.1.2 Median barriers

Median barriers are longitudinal barriers installed in the median of a divided highway to prevent vehicles from crossing the median and encountering oncoming traffic and to protect vehicles from striking a fixed object within the median.

6.5.1.3 Crash cushions

Crash cushions are a form of barrier installed to shield a fixed obstacle, adjacent to the roadway, that cannot be removed or relocated and cannot be adequately shielded by a longitudinal barrier.

6.5.2 Determining need for a barrier

Barriers are installed on the basis of warrant analyses. The Ontario Geometric Design Standards describes a warrant as a "criterion that identifies a potential need or the justification for an addition to the highway". A more descriptive definition is that:

"Warrants provide guidance to the engineer in evaluating the potential safety and operational benefits of traffic control devices and are based upon 'average' or 'normal' conditions ...The unique circumstances of each location and the amount of funds available for highway improvements must be considered in determining whether or not to install a traffic control or safety device".(Ref. 1)

Warrants are the product of committees and represent the judgment of their members. This judgment, in turn, is based on the members' professional experience and the results of research available at the time the warrant is written.

Warrant procedures have been established for implementing both roadside and median barriers and for implementing crash cushions. They are usually based on an evaluation of a barrier's relative hazard versus the hazard of an unprotected fixed object. In some cases, warrants are based on the probability of run-off-road accidents and economic factors.

Typically, roadside barrier warrants have been based on an analysis of certain roadside elements or conditions within the clear zone. If the consequences of a vehicle running off the road and striking a barrier are believed to be less serious than the consequences if no barrier existed, the barrier is considered warranted. Warrants for barrier installation have also been established by using a benefit/cost analysis that considers such factors as design speed, traffic volume, installation and maintenance costs, and collision costs.

Roadside hazards that warrant shielding by a barrier include embankments and roadside obstacles. In determining barrier need for embankments, embankment height and side slope are the basic factors used in the analysis, and produce an "equal severity curve" that compares the accident severity of hitting a barrier with the severity of going down an embankment. Barrier warrants for roadside obstacles are based on their location within the clear zone and are a function of the nature of the obstacle, its distance from the travelled portion of the roadway and the likelihood that it will be hit by an errant vehicle.

As with roadside barriers, warrants for median barriers have been established on the basis that a barrier should be installed only if the consequences of striking the barrier are less severe than the consequences that would result if no barrier existed. The primary purpose of a median barrier is to prevent an errant vehicle from crossing a median on a divided highway and encountering oncoming traffic. As such, the development of median barrier warrants has been based on an evaluation of median-crossover accidents and related research studies. In determining barrier need for medians, median width and average daily traffic volumes are the basic factors used in the analysis.

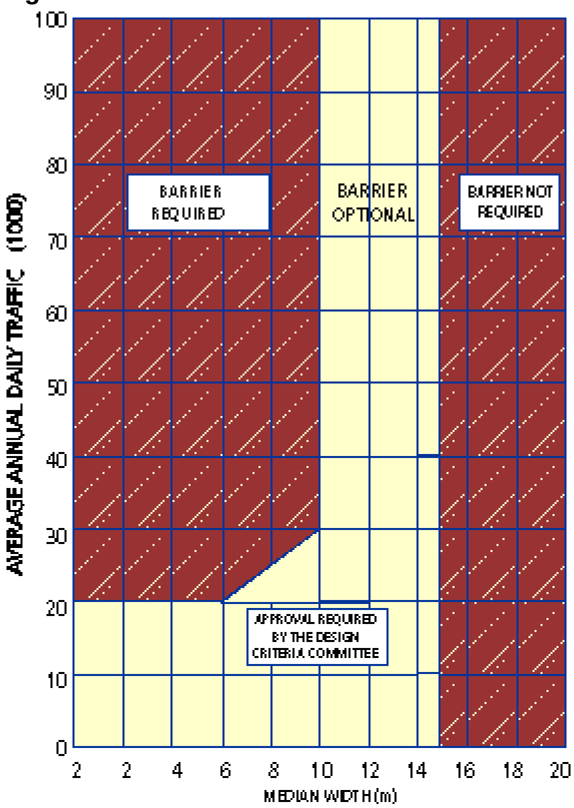
Warrants for implementing crash cushions are based on shielding a fixed object within the clear zone that is considered to be a hazard and cannot be removed, relocated, made breakaway, or adequately shielded by a longitudinal barrier.

6.5.3 Barrier issues on Highway 407

Two separate issues arise. First, whether a median barrier is required to alleviate the frequency and severity of cross-median accidents or collisions with the high-mast lighting standards and the bridge piers located in the centre of the median; second, whether the roadside barriers on ramps and along the highway are sufficient.

On cross-median accidents, the original decision not to provide a barrier was based on the "Median Barrier Warrant Guide" of the Ontario Roadside Safety Manual (Ref. 3) reproduced in Figure 6.7. It shows the conditions of traffic flow and median width under which a median barrier is deemed warranted. By the warrant, medians wider than 15m do not require a median barrier. Since the median on Highway 407 is 22.5m in width, by the manual a median barrier is not warranted.

Figure 6.7. Median Barrier Warrant Guide



The median barrier warrants used in Ontario are very similar to those in the Canadian standards (Ref. 4) which, in turn, are very similar to the warrants used in the United States. In 1960, a median barrier was deemed unwarranted in the U.S. if the median was wider than 12m. This limit has fluctuated over time, however; since 1977 it has been at 15m. For medians that are between 10m and 15m wide, the installation of a median barrier is deemed optional.

The overriding consideration in formulating a median barrier warrant is accident frequency and severity. An early study in California on the effectiveness of median barriers noted that when median barriers are installed on freeways, *"the result is a near elimination of cross-median accidents, a type of accident that often results in fatalities or injuries. However, it was also found that there would be a 20% to 30% increase in the total number of accidents"*. (Ref. 5) A more recent study in California by Seamons and Smith (Ref. 6), examined accidents before and after a median barrier was installed at 24 sites on the California freeway system. It found that after accounting for traffic growth following the barrier installation, the number of fatal and injury accidents increased by 14% and the total number of median accidents increased by 15%. The median widths in their study varied from 1.5m to 21.4m.

A review of their report shows that for medians wider than 10m, the increase in the number of fatal and injury median accidents after installation of the barrier was 25%, while for medians wider than 12m, the increase is even greater.

In view of their findings, Seamons and Smith concluded: *"the volume/median width warrant is conservative and, in most instances, provides a barrier before the number of cross-median accidents becomes significant"*.

Recently, Elvik (Ref. 7) summarized the results of 20 published studies about the effect of median barriers on safety. He concludes: *"...the best current estimates of the effects of median barriers are a 30% increase in accident rate, a 20% reduction in the chance of sustaining a fatal injury, given an accident, and a 10% reduction in the chance of sustaining a personal injury, given an accident."*

Relative to roadside barriers, Chapter 5 of this report identified a number of deficiencies in the length of the barriers installed as protection for the toll system facilities on the various ramps of Highway 407. These deficiencies generally relate to the length of the barrier as determined from the *Roadside Safety Manual* (Ref. 1), and appear to have resulted from a systematic error of calculation.

In addition, our field review has identified a number of locations where it appears that barriers may be required or, at least, a cost-effectiveness analysis should be conducted. These locations are primarily on entrance ramps from the arterial cross streets, where the combination of embankment height, ramp curvature and embankment slope present a potentially hazardous situation. The design plans indicate a slope of 3:1, which is considered to be a traversable but non-recoverable slope by the *Roadside Safety Manual*, requiring an extension of the clear zone. Similarly, the*Roadside Safety Manual* requires an extension of the clear zone on horizontal curves.

6.5.4 Comments and questions

- *Were prevailing standards met with respect to traffic barriers?*

The standards and warrants that speak to median barriers apply to medians that are substantially free of fixed objects. For such a circumstance, and in a 22.5m median, it is the committee's belief that a median barrier would likely do more harm than good. The decision not to install a median barrier in such a circumstance would be the right one and would meet prevailing standards. However, inasmuch as the high-mast light standards were located in the median, the normal standards and warrants do not apply.

Relative to the issue of the high-mast lighting standards and the bridge piers in the median, the original decision not to provide any protection was based on the clear-zone requirements outlined in the *Roadside Safety Manual*. It indicates that for a 120km/h design speed and an AADT (average annual daily traffic) greater than 6000, a 10m clear zone is required. The distance from the edge of travelled way to the high-mast light standards is greater than 10m, while the distance to the bridge piers is 10m. From that perspective, the decision was in accordance with standards.The policy on high mast lighting requires *"a minimum of 10m (desirable 15m) offset from the edge of the nearest travelled lane."* (Vol. 1, Electrical Design, 6-20, April 1990) While the minimum offset has been exceeded, the desirable offset has not been attained.

With regard to roadside barriers, there were apparent systematic errors in calculating the length of the barrier. In addition, there are a number of locations where it appears that roadside barriers should have been installed.

- *Were cost-effective opportunities to enhance the safety of Highway 407 examined and exploited with respect to traffic barriers?*

We have found no evidence that cost-effectiveness of a median barrier was examined, nor have we found evidence to suggest that the cost-effectiveness of roadside barriers and their length was examined.

- *What seemingly cost-effective opportunities to enhance the safety of Highway 407 with respect to traffic barriers exist now?*

If a median barrier were to be implemented now, it would largely nullify the concern about the obstacles that the high-mast light standards now present. However, it would result in the replacement of one obstacle by another one. The barrier would be a continuous obstacle. The question is whether the safety consequences (collisions with light standards, overturns in the ditch and cross-median accidents) of the median as it now exists are worse than the consequences of a continuous median barrier.

Our own analyses show that, considering all safety consequences, to build a median barrier now would not be cost-effective and would be detrimental to safety.

However, it may be reasonable to investigate the implementation of a crash-cushion system around each of the high-mast light standards and bridge piers. Such a system could be cost-effective. As indicated previously, there are concerns about the lack of roadside barriers along several of the ramps. Extension of the barriers installed as protection for the toll system facilities would serve to alleviate these concerns. However, analysis is required to determine whether this would be cost-effective.

6.5.5 Recommendations

- *What should be examined?*

1. Investigate the technical problems and costs of implementing a crash-cushion system around each of the high-mast light standards and bridge piers in the median. Depending on the cost of the system, site preparation requirements, and the system's format, such a system could be a cost-effective solution to alleviate the expressed concerns of the presence of the high-mast lighting standards and enhance the safety of the highway.
2. Investigate the various ramp locations on the roadside, particularly on the entrance ramps from the arterial roadways, where the combination of embankment height, ramp curvature and embankment slope, create a potentially hazardous situation, to determine whether the installation of a barrier in these locations is cost-effective.

6.5.6 References

1. California Department of Transportation, *Traffic Manual. Section 1-04 Nomenclature*, Sacramento, C.A., 1978.
2. *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances*, National Cooperative Highway Research Report 230, March 1981.
3. Ministry of Transportation of Ontario. *Roadside Safety Manual, Downsview*, 1993.
4. Transportation Association of Canada, *Manual of Geometric Design Standards for Canadian Roads, Metric Edition*, Ottawa, 1986, p. F-24.
5. Johnson, R.T. "Effectiveness of Median Barriers," *Highway Research Record 105*, 1964, pp. 99-112.
6. Seamons, L.L. and R.N. Smith. Past and Current Median Barrier Practice in California, Caltrans-TE-90-2, California Department of Transportation, June 1991.
7. Elvik, R. "The Safety Value of Guardrails and Crash Cushions: A Meta-Analysis of Evidence from Evaluation Studies," *Accident Analysis and Prevention*, Vol. 27, No. 6. 1995.
8. Steers, Sgt. J.L. *An Analysis of Hwy 403 Motor Vehicle Cross Over Collisions Occuring in the Port Credit Detachment Area*, Ontario Provincial Police, September 1996.

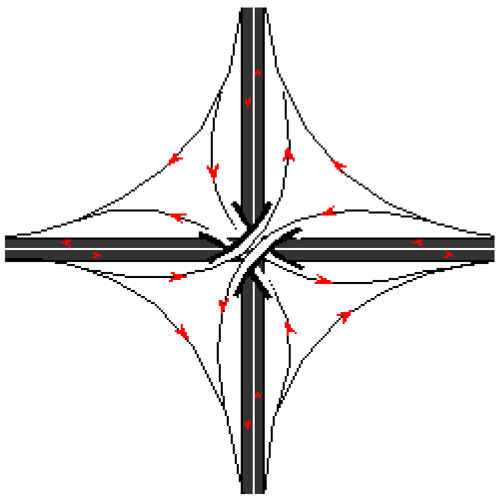
6.6 Interchange ramps

6.6.1 Introduction

The following discussion is based on the stated classification of Highway 407 as a rural freeway. Some members of the committee have questioned the advisability of this classification for Highway 407. Their opinion generates some different conclusions, which are discussed in Sections 6.6.5 and 6.6.6.

A ramp is typically defined as a turning roadway that permits the movement or interchange of traffic between two intersecting freeways, or between a freeway and an intersecting arterial highway/roadway.

Figure 6.8. Fully directional four-level interchange



In the case of freeway-to-freeway interchanges, it is normal practice in Ontario to design what are called directional interchanges. MTO describes these as:

"... fully-directional interchanges provide for right and left turns through large radius ramps having design speeds in the order 70% to 80% of the freeway design speeds and having overall deflection angles in the order of 90 degrees." (Ref. 1) The reason for selecting directional ramps with a relatively high design speed is explained by MTO:

It's rarely feasible to provide ramps in the same range of speeds as on the through roads, but it is desirable that drivers be able to use ramps at as high a speed as practicable so that there will be little conscious effort required in a decrease from or an increase to the speed of through traffic. The design of the ramp, therefore, is related to the design speed of the intersecting roads. The view of a structure, its ramps and approach signing encourage drivers to slow down. Most drivers are willing to reduce speed if the reduction is not excessive, and if they can traverse the ramp at a reasonable speed." (Ref. 2)

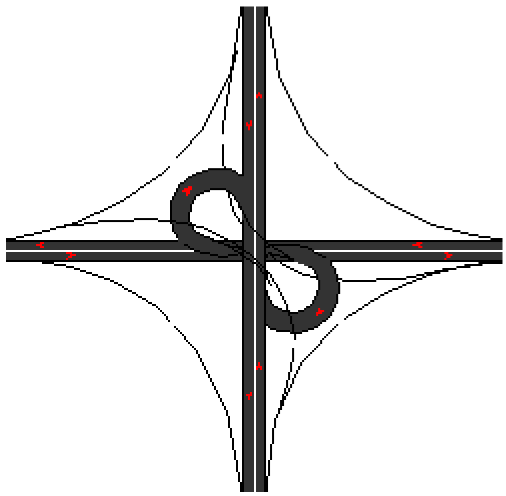


Figure 6.9. Partially directional interchange with inner loop ramps

An important implication of fully directional interchanges is that the accommodation of all turning movements on high-speed ramps requires four levels to separate the ramps as depicted in Figure 6.8. As a result, the cost of providing the necessary ramp structures (bridges) can be quite high.

In recognition of the desirability to reduce cost when feasible, MTO advises:

"partially directional interchanges [see Figure 6.9.] *provide for some left-turn movements by means of loop ramps, which have lower design speeds. Partially directional interchanges have applications where there are severe property limitations, significant environmental impact, or where some left-turn volumes are low."* (Ref. 1)

When arterial roadways intersect higher-speed freeways, the provision for left-turn, inner loop ramps is much more common, and, in fact, some left turns can occur only in at-grade intersections on the arterial roadway. A typical interchange of this type is illustrated in Figure 6.10 (the Parclo A-4 is commonly used in Ontario, and on Highway 407).

Since the OPP raised concerns about the design of loop ramps on Highway 407, the committee deemed it worthwhile to review this matter in a reasonable amount of detail. In addition, since the consortia value engineering exercises contained recommendations that reduced design speeds on directional ramps, and converted directional ramps to loop ramps, both ramp types are discussed below in the freeway-to-freeway application.

6.6.2 Freeway-to-freeway ramps

MTO has for many years provided very explicit standards for ramp design at freeway-to-freeway interchanges. Specifically, designers are apprised of the minimum design speeds required:

"Guide values for ramp design speed in terms of highway design speed are shown in Table F5.1. To cover the wide variety of interchange types and site conditions the ramp design speed is shown as a range between standard and minimum. Ramp designs are based on the standard design speeds where feasible. Where ramps so designed are out of balance with the interchange or are unduly costly, a lower

design speed is appropriate. Selection of ramp design depends upon the type of intersecting roads and the site controls. For outer loops and direct ramps from crossing roads, the standard values of design speed given in Table F5-1 are used." (Ref. 1)

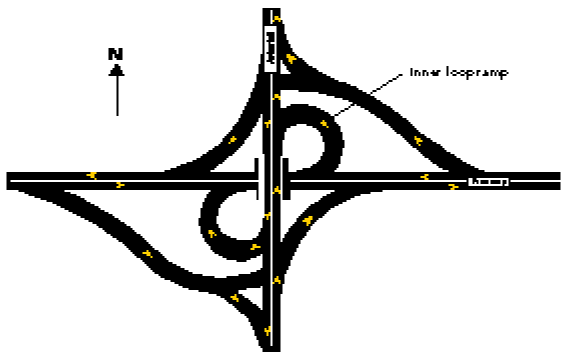


Figure 6.10. Arterial-to-freeway interchange (Parclo A-4)

The reference to Table F5-1 was made in both the 1986 and 1994 MTO design manuals and the relevant entries for a rural freeway divided with a design speed of 120 km/h are presented in Table 6.1.

Table 6.1. Ramp Design Speed (excerpts from Table F5-1, MTO Geometric Design Standards)

	1986	1994
Highway design speed, km/h	120	120
Ramp design speed, km/h desirable (1986) standard (1994) minimum	100 60	80 60
Minimum radius, m (superelevation = 6%) desirable (1986) standard (1994) minimum	420 130	250 130

We note here that the minimum radii are defined based on a maximum superelevation rate of 0.06 m/m or 6%. This is in accord with MTO policy for rural highways of all types. In addition, based on our review of Highway 407 project design criteria, the 1986 radii were taken as the standard in the vast majority of the cases. Of course, this is not surprising, given the explicit documentation in the MTO *Geometric Design Standards Manual*, and given that much of the Highway 407 design predated 1994.

In summary, the prevailing standards call for directional ramp design speeds in the range of 80 km/h (1994) to 100 km/h (1986) with respective minimum radii from 250m to 420m.

Inner loops have a minimum design speed of 60 km/h with the equivalent minimum radius of 130m. Traffic on the inner loop ramp enters from the freeway at or close to freeway speed (100 km/h to 120 km/h) and is required to reduce speed to that of the minimum radius curve, known as the controlling radius. The reduction in speed takes place over a spiral curve, which is a curve of steadily decreasing radius between the freeway and the controlling radius. These types of ramps are a safety concern in which the most common type of accident is one in which a vehicle does not reduce speed sufficiently to negotiate the controlling curve and runs off the road on the left.

On the section of Highway 407 under study, there are four freeway-to-freeway interchanges at Highways 410, 400, 427, and 404. The one at Highway 400 has four levels, no inner loops, and is therefore **not a concern.**

The interchange at Highway 410 was originally designed as a four-level interchange and later was reduced to three levels, by introducing inner loops in the northeast and southwest quadrants, carrying traffic from Highway 410 to Highway 407. Highway 410 passes under Highway 407 and therefore both inner loop ramps are on up-grades, which is beneficial in helping to reduce speed on the spiral curve. The up-grade configuration also provides a good view of the ramp surface ahead, which also helps the driver to negotiate the controlling radius curve.

The controlling radius of the inner loop is 90m, which is better that the minimum 75m in the RFP design criteria, **but less than the MTO minimum of 130m.** The superelevation on the controlling radius curve is 6%. In fact, most inner loop ramps on Highway 407 have 8% superelevation. Although the difference between 6% and 8% is not particularly significant, an opportunity to ameliorate the safety weakness of the inner loop ramp has been lost. Overall, the controlling radius, the up-grade and the good view of the ramp surface make the inner loop ramps at this location less of a safety concern than many of the other inner loop ramps.

The interchange at Highway 404 has Highway 407 passing over Highway 404 with inner loop ramps in the northwest and southeast quadrants. The radius of the ramps is 75m, which meets the RFP design criteria but not the MTO minimum standards. Since Highway 407 passes over Highway 404, the inner loop ramps are on downgrades. This configuration does not encourage a vehicle to reduce speed and does not provide a driver with a good view of the ramp surface.

In the case of the Highway 410 and 404 interchanges, the decision to develop three-level interchanges with two inner loop ramps rather than four-level interchanges appears to have been driven by cost-saving considerations, apparently accepting the safety weaknesses discussed above.

If any of these ramps proves to be a safety concern when the highway is in operation, the interchanges are so permanent that the only remaining remedial treatments are signing and other traffic control measures.

In the interchange at Highway 427, Highway 407 passes over Highway 427 with inner loops in the southwest and southeast quadrants. The radii of these two ramps are 45m, which does not meet the minimum of 75m in the RFP design criteria and corresponds to a design speed of approximately 36 km/h. **The radius of 45m is substandard for an inner loop ramp between two freeways.**

6.6.3 Arterial-to-freeway ramps

As suggested earlier, some ramp design speeds at arterial-to-freeway interchanges can be lower, because the intersecting arterial roadway has a design speed lower than a freeway.

In this case, the design speeds of ramps exiting the arterial road and entering the freeway would be selected from the aforementioned Table F5-1, using the design speed of the arterial roadway. However, ramps exiting Highway 407 and entering the arterial roadway would have design speeds selected as described previously, that is using the freeway design speed of 120 km/h.

In the Highway 407 corridor, for example, design speeds of arterial roadways are typically in the range of 80-100 km/h.

The relevant additional information has been extracted from Table F5-1 as summarized in Table 6.2.

Table 6.2. Ramp Design Speed (excerpts from Table F5-1, MTO Geometric Design Standards)								
	1986				1994			
Highway design speed, km/h	80	90	100	120	80	90	100	120
Ramp design speed, km/h desirable (1986) standard (1994) minimum	 70 40	 80 50	 80 50	 100 60	 60 40	 70 50	 70 50	 80 60
Minimum radius, m (superelevation = 6%) desirable (1986) standard (1994) minimum	 190 55	 250 90	 205 90	 420 130	 130 55	 190 90	 190 90	 250 130

In addition to the standards in Table 6.2, we note that the RFP design criteria call for a minimum radius of 75m for inner loop ramps. If we use a design speed of 90 km/h (mid range) the desirable/standard design speeds for the outer directional ramps would be 70 km/h (1994) to 80 km/h(1986); the corresponding minimum radii would be 190m to 250m.

For inner loop ramps, the minimum design speeds would be 50 km/h for both the 1986 and 1994 standards; the corresponding minimum radius is 90m.

All the arterial inner loop ramps on Highway 407 have radii of 50m, except at Keele Street and Bayview Avenue, where they are 55m, and at Bramalea Road, Highway 27 and Pine Valley Road, where they are 45m. Therefore, the vast majority of the loop ramp radii do not meet the standards.

The superelevation on these inner loop ramps is 8%, except at Highway 27, where it is 6%. Consistency would be preferable.

It is important to note that the radius for Kipling Avenue and the superelevation information for Kipling Avenue, Pine Valley Road and Jane Street were not available for this safety review.

6.6.4 Comments and questions

- *Were prevailing standards met with respect to **freeway-to-freeway** directional ramp radii and superelevation rates?*

For the most part, yes. It appears that most of the directional ramps have design speeds at or exceeding 80 km/h, with superelevation applied at the rate of 6%, in accordance with MTO policy.

We understand that a few directional ramps were constructed with radii less than called for by the minimum standard. In at least one of these cases, superelevation was applied at the rate of 8%, and is therefore inconsistent with MTO policy.

In addition, some previously planned directional ramps were changed to loop ramps without explicitly considering the safety consequences. The lack of explicit analysis is of concern to the committee.

- *Were prevailing standards met with respect to **freeway-to-freeway** loop ramp radii and superelevation rates?*

No. For freeway-to-freeway interchanges, some ramps have radii significantly less than the minimum 130m called for by the standards. Some ramps have radii significantly less than the minimum 75m put forth by MTO in the RFP. Some ramps have radii as low as 45m, with a corresponding design speed of approximately 36 km/h. This is of great concern to the committee.

Some ramps are superelevated at the rate of 6%, while many others are superelevated at 8%. This inconsistency in design is of concern to the committee.

- *Were prevailing design standards met with respect to arterial-to-freeway loop ramp radii and superelevation rates?*

No. The vast majority of arterial-to-freeway loop ramps have radii less than both MTO and RFP design criteria standards call for. Given the relatively high approach speeds that can regularly occur on these roadways, this is of concern to the committee.

We also note some inconsistency in the application of superelevation; the true extent of the inconsistency is unknown, because the superelevation at several locations was unavailable to us.

- *What seemingly cost-effective opportunities to enhance the safety of Highway 407 exist now with respect to ramp design?*

The interchanges with structures and ramp roadways are built and therefore permanent. Little opportunity remains to enhance safety through design. However, positive guidance measures to warn drivers in advance of low-design-speed ramps could be considered. In addition, measures to increase surface friction could be considered.

Also, intelligent transportation systems-based technology could be considered for heavy truck rollover notification on some of the more problematic loop ramps, if commercial traffic volumes, truck types and accident experience justify it.

6.6.5 Alternative opinion

The discussion in 6.6.1, 6.6.2 and 6.6.3 is based on the stated classification of Highway 407 as a rural freeway. Some members of the committee have questioned the advisability of this classification for Highway 407, and their opinion generates some different conclusions on the resultant design. This alternative opinion is explained and the consequences are discussed below.

Highway 407 is unusual in that it does not have typical characteristics of either a rural or an urban freeway. A rural freeway normally has no more than four lanes, a wide median, low volumes of traffic, long trip lengths and is not illuminated. It is typically set in a rural surrounding with little development.

An urban freeway, on the other hand, usually has at least six lanes, a narrow median, high volumes of traffic, short trip lengths and is illuminated. Typically, it is set in an urban area of development (often industrial or commercial).

Highway 407 follows an alignment through suburban Toronto, which is already developed to a considerable degree, and new development is continuing. It is our view that the highway is already of the nature of an urban rather than a rural freeway, and that, once opened, it will continue to exhibit more of the characteristics of an urban facility. This is the history of the development of Highway 401 from Mississauga to Oshawa, which functions as an urban freeway.

When Highway 407 was first conceived, the surrounding area was largely farmland and undeveloped. Today, it is largely developed. It is our opinion that for the purpose of design, an urban classification would have been more appropriate. The classification of a road gives direction to the designer on selecting many of the elements and dimensions of the road and in applying standards.

Highway 407 has six lanes at Stage 1, with capability for widening to eight lanes and eventually 10 lanes as traffic volumes increase with the further urbanization of the area. In the case of freeways, the classification influences ramp radii and maximum superelevation on ramps. The classification selected at the outset has some far-reaching consequences. If Highway 407 is treated as an urban freeway, the following standards apply.

Table 6.3. Ramp Design Speeds for Urban Freeways		
	1986	1994
Highway design speed, km/h	120	120
Ramp design speed, km/h desirable (1986) standard (1994) minimum	 100 60	 80 60
Minimum radius, m (e=8%) desirable (1986) standard (1994) minimum	 380 120	 230 120

Table 6.3 applies to directional ramps leading from a freeway to either a freeway or an arterial road.

For interchange inner loop ramps leading from an arterial road to a freeway (Parclo A), Table 6.4 values apply.

Table 6.4. Ramp Design Speeds for Urban Interchange Loop Ramps Leading from an Arterial Road to a Freeway		
	1986	1994
Highway design speed, km/h	80	80
Ramp design speed, km/h desirable (1986) standard (1994) minimum	 70 40	 60 40
Minimum radius, m (e=8%) desirable (1986) standard (1994) minimum	 170 50	 120 5

The urban classification permits the application of 8% superelevation and smaller radii on loop ramps, by the use of a standard Parclo A4 interchange, which is extensively used throughout southern Ontario.

6.6.6 Comments and questions (alternative opinion)

The classification of Highway 407 as a rural freeway was in our view inappropriate; an urban classification would have been more suitable. In fact, for the purpose of designing the arterial-to-freeway interchanges, the urban classification appears to have been adopted.

- *Were prevailing standards met with respect to freeway-to-freeway directional ramp radii and superelevation rates?*

For the most part, yes. However, the Highway 410 interchange was designed with 6% superelevation.

- *Were prevailing standards met with respect to freeway-to-freeway loop ramp radii and superelevation rates?*

No. The standards call for a minimum of 120m and some are significantly less than this, particularly at Highway 427, where the radius is 45m. Superelevation was generally 6% rather than 8%.

- *Were prevailing design standards met with respect to arterial-to-freeway loop ramp radii and superelevation rates?*

Yes, for the most part. The majority of inner loop ramps have radii of 50m or more. A few have radii of 45m, which is not a serious concern. Generally, 8% superelevation was applied with some exceptions. This difference may have arisen from some designers following the classification of rural, while others assumed an urban environment.

- *What seemingly cost-effective opportunities to enhance the safety of Highway 407 exist now with regard to ramp design?*

Opportunities are limited, because the interchanges are built and are therefore permanent. Some enhancement could be made by using such traffic control devices as signage and markings and measures to increase surface friction.

6.6.7 Recommendations

Regardless of what the classification of the highway should have been, a classification must be enunciated, as a matter of policy, and then followed by all who engage in design. Failure to do so in this project resulted in uncertainty as to what the appropriate standards are and in consistency in some design.

- *What should be examined?*

The committee did not have the time to examine promising courses of action, let alone determine which, if any, might be cost-effective improvements. We recommend that among other possible means to reduce the frequency and severity of accidents, the following options be considered:

1. all ramps be tested and corresponding advisory speeds be posted, with signs of prominent size at prominent locations in the event this has not already been done;
2. the provision of barriers on the outside of all short-radius ramps be considered;
3. the provision of chevron alignment signs on the outside of all short-radius ramps be considered;
4. the provision of "tipping trench" or checkerboard signs on short-radius ramps be considered;
5. the provision of ITS-based rollover notification be considered;
6. measures to increase the ramp surface friction be considered; and
7. the possibility of increasing superelevation to 8% on those ramps with lower superelevation.

The processes that led to the design of many short-radius ramps were not based on defensible safety analyses. In this regard, the committee emphasizes that decisions that will have such long-lasting and potentially substandard impacts on the future safety of a road must consider safety consequences explicitly, using the best information available at the time and be conducted by engineers with safety experience.

During our review of the issue of ramp design, we encountered several interpretations as to how one should "apply" the standards. In addition, we note that the 1994 standards call for significantly lower "standard" design speeds than was the case in 1990 and before. We could find no justification based on safety analyses to support such reductions.

MTO should revisit the standards and policies to assess the onsite safety experience to date and the research in this area, and to issue such revisions and/or explicit guidance as called for.

6.6.8 References

1. Ministry of Transportation of Ontario. *Geometric Design Standards for Ontario Highways*, 1994, p.F5-2.

6.7 Acceleration lane lengths

6.7.1 Overview

The Ministry of Transportation developed new standards for geometric design of highways in the late 1970s to supersede standards in imperial units. Standards for acceleration lane lengths on freeway entrances are shown in Table 6.5.

Table 6.5. 1970s Standards for Acceleration Lane Lengths on Freeway Entrances

Freeway Design Speed	Acceleration Lane Length (measured from bullnose to end of taper)
80 mph	1625ft
74.58 mph (120 km/h)	1462ft (445m) by interpolation
70 mph	1325ft

These values were calculated based on certain assumptions of speed and other driving characteristics, and the calculated values rounded to the nearest 25 ft. In developing the standards in metric units, they reviewed assumptions on which the standards were based for validity and in some cases revised them to match the current conditions. The calculated values were rounded to the nearest 10m.

The current standard for a freeway acceleration lane is 500m. The developer of Highway 407 was permitted by the RFP to utilize a length of 446m, which was derived as follows.

- The design speed of Highway 407 is 120 km/h (equal to 74.58 mph), which falls between 70 mph and 80 mph. By interpolating linearly, this gives a length of 1462 ft, which when expressed in metric units is 446m.

In summary, a standard acceleration for lane lengths that prevailed in the 1970s was used for Highway 407, apparently without referring to either the current 1996 standards or the reasoning used for increasing the length when the old standards were updated. If the old standard had been considered satisfactory, the new standard would probably have been set at 450m.

The consequences of this are not serious from a safety aspect. There is, however, a minor loss of service in the merge manoeuvre, because the driver has less distance and time to complete the merge. This may not be significant for cars, but is more important for trucks.

6.7.2 Comments and questions

- *Were prevailing standards met with respect to acceleration lanes?*

While a deficiency was noted across the board on this parameter, we do not regard it as serious from a safety standpoint. CHIC was given permission by the request for proposals to use 446m.

- *Were cost-effective opportunities to enhance the safety of Highway 407 examined and exploited with respect to acceleration lanes?*

It would appear that this question was not examined.

- *What seemingly cost-effective opportunities to enhance the safety of Highway 407 with respect to acceleration lanes exist now?*

There appear to be few, if any, cost-effective safety opportunities to remedy the minor deficiencies that currently exist with respect to acceleration lane lengths.

6.8 Slope at the road's edge

6.8.1 Overview

Highways are designed to have grades that are as mild as the topography allows. To make them so, embankments are created in hollows and cut on hill sides. If interchange structures are excluded, a large part of the cost of highway construction is found in these cut and fill requirements. Within the limits of what is practical, the steeper the side slope, the less the cost of earthwork. Steeper slopes also minimize the width of right-of-way required. On the other hand, steep embankments create a safety hazard for errant vehicles. Thus the choice of roadside side slope must be balanced between construction cost and safety.

6.8.1.1 Definitions

The definitions of the embankment elements are given in Figure 6.11. This is an example of a highway that is cut into a hillside. The front (or side) slope leads from the shoulder to a drainage ditch of some width, after which there is a back slope in the cut section. The drainage ditch is designed for the controlled removal of water from the edge of the highway. The depth of the ditch must also be sufficient to keep water from infiltrating into the road bed. Slope, by tradition, is defined as the ratio of the horizontal distance to one unit of fall or rise. For example, a 6 to 1 slope is noted as 6:1 and has a 6m horizontal distance for 1m vertical change. The vertical direction is noted as a rise or fall, unless it is obvious from the nature of the text.

The different slopes are joined by rounding. The rounding occurs over a metre or more and is designed to allow the vehicle to go smoothly from one slope to another without becoming airborne.

6.8.1.2 Operating experience

Designing roadside ditches, particularly those in the median, is a complex task, involving many conflicting factors. Engineers must consider right-of-way, storm water drainage, sediment control, speed of water flow, water seepage into the roadbed, environmental issues, future road expansion and safety. So the task of selecting a side slope, which at first appears to be straight forward and simple, is actually very involved and requires considerable engineering analysis and judgment.

In the clear-zone discussion (Section 6.4.1) we noted that for errant vehicles, side slopes may or may not be traversable or indeed a hazard. By general agreement among road authorities, a front (side) slope of 2:1 or steeper is considered a hazard. A smooth unobstructed slope between 3:1 and 4:1 is considered traversable but non-recoverable. On these slopes, vehicles may be able to go down safely, but the driver will not be able to recover control. Slopes of this steepness will have the recovery area beyond the toe of the side slope. Slopes of 4:1 or flatter are defined as recoverable and traversable, if free of obstructions.

The relative rating of roadside slopes as given in the Institute of Transportation Engineers' Traffic Safety Toolbox (Ref. 1) are:

- 2:1 - hazardous;
- 3:1 - marginal;
- 4:1 - good;
- 6:1 - better;
- 10:1 - preferred.

The safety of a side slope depends both on the steepness of the slope and the height of the embankment (see Figure 6.11). *The Roadside Safety Manual* (Ref. 2, p. 0205-2) defines a critical slope as *"one on which a vehicle is likely to overturn"*, which they consider is usually steeper than 3:1. On divided highways, fill heights greater than 2m and side slopes steeper than 3:1 are enough of a hazard to warrant guardrails, if they occur within the suggested clear zone.

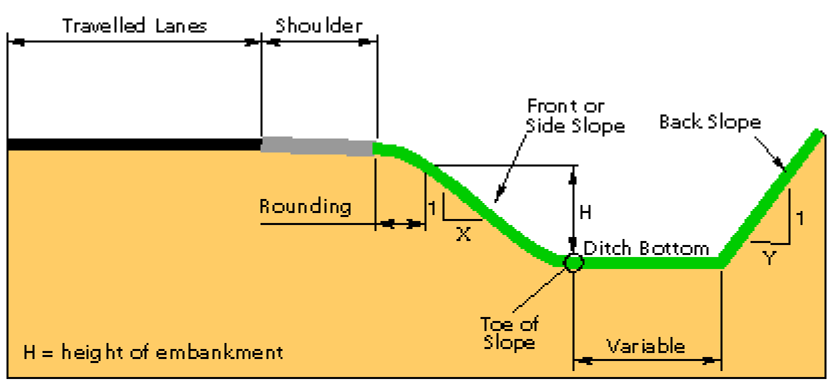


Figure 6.11. Embankment elements (not to scale)

A guardrail is warranted for interchange ramps with a speed of less than 80 km/h when the fill height is greater than 3m, and the side slope is 3:1 or steeper, if they occur within the recommended clear zone, because these conditions are a hazard.

The Transportation Association of Canada in the *Manual of Geometric Design Standards* (Ref. 3, p. c-31) and MTO in the *Geometric Design Standards for Ontario Highways* (Ref. 4, p. D.8-1) state:

"On freeways ... with reasonably wide roadsides, side slopes on embankments and in cuts should be designed to provide a reasonable opportunity for recovery of an out-of-control vehicle".

Both publications go on to recommend embankment slopes of 6:1 or flatter so a vehicle has a reasonable chance of recovery and state: "Steeper slopes up to 4:1 may be traversable where the height is moderate and the rounding at the bottom is generous."

The typical cross-section drawing from TAC's Figure C.13.6, Rural Freeway Divided gives a side slope of 6:1 (even for rock cuts), a drainage-ditch channel of 2.5m and a cut back slope of 2:1. The steepness of the back slope is apparently permitted.

The MTO Geometric Design Standards notes:

"Median Side Slopes should be no steeper than 4:1. Flatter slopes are beneficial to safety ... . Flatter slopes should be used where feasible in terms of cost and property." (Ref. 2, D.5.2.1, p. D6-1). Elsewhere it comments: "A median width between 10m and 15m with 10:1 slopes does not usually require a traffic barrier and is considered to be the optimal median concept". (Ref. 2, D.6.1, p. D6-1).

California considers that side slopes 3:1 or flatter will generally eliminate the need for guardrails (Ref. 5, 304.0, p. 300-3). Median side slopes should be 10:1 or flatter and 20:1 is preferred (Ref. 5, 305.2 p. 300.5).

Zegeer et al. (Ref. 6) wrote: *"Side slopes need to be flatter than 5:1 to significantly reduce the probability of vehicle rollovers"*. Graham and Harwood (1982) in an early study of the effectiveness of clear zones found that for average daily traffic volumes of 5000 vehicles on two-lane rural highways, there were roughly twice the accidents on roads that had a clear-zone slope of 4:1 than there were on similar roads with clear-zone slopes of 6:1. AASHTO (Ref. 7) suggests that slopes of either 6:1 (p. 4) or 10:1 (in Figure F. 3.5) are desirable.

6.8.1.3 Ontario standard

MTO standards and policies allow maximum slopes of 2:1. A side slope between 4:1 and 3:1 is non-recoverable, but if clear of obstruction is traversable. Slopes steeper than 3:1 are a hazard.

Critical slopes are defined for divided highways as slopes steeper than 3:1 on embankments higher than 2m within the recommended clear zone. Interchange ramps with speeds less than 80 km/h have a critical slope when it is steeper than 3:1 on a 3m fill starting within the recommended clear zone.

The MTO Geometric Design Standards encourages designers to use side slopes flatter than 4:1 and suggests that the best median slope is 10:1.

6.8.2 Comments and questions

- *Were prevailing standards met with respect to side slope requirements?*

In the sections of Highway 407 reviewed by the committee, the Ontario standards were met. The standards suggest flatter slopes where possible, but no documented evidence of flatter side slopes being considered was found. Within certain portions of the median, side slopes flatter than 4:1 were observed. There was some limited use of flattened slopes within the median, but generally the committee felt that the minimum design standards were employed and that the spirit of trying to use flatter slopes as proposed by the MTO standards was not undertaken.

- *Were cost-effective opportunities taken to enhance safety of Highway 407 examined and exploited with respect to road side slopes?*

The typical cross-section adopted in the preliminary design phase design criteria endorsed on June 30, 1983 had median side slopes of 4:1. There is reference in the June 30 memo to using slopes as steep as 3:1 and 2:1to reduce the need for right-of-way. It appears that the steepest allowable side slopes were employed.

We found no evidence that cost-effectiveness of slope design was considered.

- *What seemingly cost-effective opportunities to enhance safety of Highway 407 with respect to side slopes now exist?*

The transition areas between differing slopes should be reviewed to permit the smooth movement of a vehicle from one slope to another, also some slopes could probably be cost-effectively flattened.

6.8.3 Recommendations

- *What should be reviewed?*

Along the right side of the highway, the side slopes should be reviewed to see if they could be flattened. Some fill heights along the outside of the road are high and at the bottom are both major drainage structures and large-capacity ditches. The safety of these locations should be reviewed.

The interchange ramp side slopes checked by the committee were mostly 3:1, which meets the minimum standard. However, the committee felt that some of the ramp fill heights were quite high and that guardrail protection or slope flattening should be reviewed, particularly on inner loop ramps.

The estimated value of the Severity Index of the V-ditch in some lengths of the median is 3. If the median V-ditch had a more rounded bottom, the Severity Index would be reduced to about 2. The impact of rounding the bottom of the V-ditch for safety purposes should be reviewed and balanced against the drainage requirements. In addition, the transition areas between differing slopes should be reviewed to permit the smooth movement of a vehicle from one slope to another. Also some slopes could probably be flattened.

- *Considerations for the future*

Designers need to be reminded of the sections of the Geometric Design Standards for Ontario Highways that require safety to be considered and that advise that side slopes flatter than 3:1 be considered. There needs to be more explicit policy direction given by the ministry to designers about consciously considering safety in roadside design.

6.8.4 References

1. Institute of Transportation Engineers. *Traffic Safety Tool Box*, Washington, D.C., 1993.
2. Ministry of Transportation. *Roadside Safety Manual*, Downsview, 1993.
3. Transportation Association of Canada. *Manual of Geometric Design Standards for Canadian Roads*, Ottawa, 1986.
4. Ministry of Transportation. *Geometric Design Standards for Ontario Highways*, Downsview, 1994.
5. California Department of Transportation, *Highway Design Manual, 4th edition*, 1990.
6. Zegeer, C., Twomey, J., Heckman, M. and J. Hayward. *Safety Effectiveness of Highway Design Features, Volume II, Alignment*, Report No. FHWA-RD-91-045, Washington, D.C., 1992.
7. American Association of State Highway and Transportation Officials. *Roadside Design Guide*, Washington, D.C., January 1996.

6.9 Pavements

6.9.1 Overview: Role of highway pavements

Pavements_the top layer of a road structure_fulfill three important roles:

- They provide the riding surface for a vehicle using the road.
- They seal the road structure from water penetration and thus help protect the remainder of the structure from structural damage.
- Working with the underlying road structure, they provide structural strength for the road, allowing it to support the vehicles using it.

From the standpoint of road safety, it is the first of these roles that is most important. The surface pavement must provide a smooth and comfortable ride that allows the driver to easily retain control of the vehicle. In addition, it must be constructed with a cross-section that allows water to drain away easily from the travelled lanes to the adjacent ditches or curb and gutter, to ensure that in wet conditions vehicles can retain contact with the surface and avoid loss of control due to hydroplaning. Finally, in both slippery and dry conditions, the road surface must provide sufficient friction to allow drivers to be able to stop and steer in a safe and controlled manner.

6.9.1.1 Types of highway pavement

Three types of pavement structure are used in Canada for major roads:

- asphaltic concrete highways, which consist of a granular base substructure and one or more layers of asphaltic concrete;
- Portland cement concrete (PCC) highways, which consist of a granular drainage layer substructure and a Portland cement concrete pavement;
- composite pavements, which combine a granular substructure, Portland cement concrete base pavements and an asphaltic concrete pavement wearing course.

About 97% of the paved roads in Canada are of the asphaltic concrete type. Extensive use of Portland cement concrete (PCC) pavements has been made in two major Canadian cities: Winnipeg, Manitoba, and Windsor, Ontario. In the U.S., about 60% of the interstate highway system uses PCC pavements. The decision on what type of pavement structure will be used is usually based on both functional and economic considerations. All three pavement types can and have been used effectively for major urban and interurban highways. Value engineering analyses and life-cycle costing are commonly used in determining the final type of pavement to be used.

6.9.1.2 Highway 407 pavement choice

The request for proposals for Highway 407 indicated that a composite pavement structure was to be used. In its value engineering proposals, Canadian Highways International Corporation (CHIC) indicated that it would use such a pavement, whereas Ontario Road Development Corporation (ORDC) suggested an asphaltic concrete pavement design (Ref. 1). In its final proposal, CHIC selected a PCC pavement structure based on a life-cycle cost analysis of various pavement design options (Ref. 2). The analyses were carried out using a variety of pavement design procedures (OPAC, AASHTO, PCA) as appropriate and assumed that traditional MTO materials, specifications and procedures would be used. Appropriate maintenance assumptions were also included in the life-cycle cost analyses, including the need for retexturizing PCC pavement surfaces at both the 10- and 20-year points to ensure proper drainage and skid resistance (Ref. 3)

6.9.1.3 The question of skid resistance

Skid resistance is a critical safety-related property of highway pavements. Mix designs and material specifications for both asphalt and PCC pavements are conceived in such a way as to ensure that the pavement provides an appropriate level of skid resistance, initially and over time. In addition, skid resistance on PCC pavements is normally assured through the use of a burlap drag and subsequent tining technique during the construction process, to provide the appropriate microtexture and macrotexture needed for specified skid-resistance levels. In-field examination of the road surface indicated that the normal construction processes had been carried out throughout the project with the result that the surface is consistent with what would normally be expected on an acceptably performing PCC pavement.

6.9.1.4 Maintenance: the critical ingredient

Maintenance is the critical factor in ensuring adequate pavement performance over time. As noted earlier, our review of CHIC's life-cycle cost analysis found that it incorporated the normal maintenance and rehabilitation measures we would expect to see associated with a PCC pavement, both with respect to the maintenance of an adequate skid-resistant surface and other functional qualities expected of a highway pavement.

6.9.2 Comments and questions

- *Were prevailing standards met with respect to pavements?*

Yes. While the original stipulation of a composite pavement design by MTO represented its most common practice, the use of PCC pavements was also allowed and accounted for in their normal standards and specifications.

- *Were cost-effective opportunities to enhance the safety of Highway 407 examined and exploited with respect to pavements?*

Close attention was given to the design and value engineering analysis of pavement options. The in-field examination of the pavement shows that positive actions were taken with respect to the use of appropriate techniques during the construction process to ensure that initial skid resistance would meet required specifications. In addition, the life-cycle costing analyses specifically recognized and incorporated the need for maintenance measures to ensure continuing skid resistance performance over the life cycle of the pavement.

- *What seemingly cost-effective opportunities to enhance the safety of Highway 407 with respect to pavements exist now?*

It appeared to the committee that CHIC took good advantage of the opportunities available to it to ensure the initial and continuing safety of the pavements on Highway 407, during the design and construction of the project.

6.9.3 Recommendations

Although it is not our role to review planned maintenance practices, it would be prudent to ensure that the developers have in place an appropriate pavement management program to allow for tracking actual pavement performance over time, to assure that any additional remedial programs that might be required as a result of unanticipated developments (e.g. higher volumes of traffic than forecast, greater proportions of commercial traffic, etc.) are initiated as needed.

6.9.4 References

1. Canadian Highways International Corporation. *Phase One, Part I-Value Engineering*, August 1993.

2. Canadian Highways International Corporation. *Proposal: Volume 1. Appendix A-5: Pavements*, p. A-5.11.
3. Canadian Highways International Corporation. *Proposal: Volume 1. Appendix A-5: Pavements*, pp. A-5.52-55.
4. Signs and markings

6.10 Signs and markings

The committee did not comprehensively evaluate the signs and markings on Highway 407. Based on our field visits, the highway's signs and markings appear to follow accepted standards and practice. However, inasmuch as this is the first fully electronic toll road in North America where drivers will not have the option of paying by cash or credit card, we asked a human-factors consultant to examine the highway.

The consultant notes that the signs in advance of the toll gantries do not tell drivers what cost they can expect, or that toll collection is automatic and that they are not required to stop at the gantry. Concern has been expressed that some drivers will not realize that they are on a toll road until they see the gantry with the cameras, which may cause them to slow down, stop, or even attempt to back up the ramp. It is the experience of the Dulles Greenway Toll Road Operations Centre (where payment is either by a transponder or by credit card) that, even after three years in operation and with 25,000 vehicles each day, some 20-25 drivers call the operator from the toll booth each day trying to arrange for payment by some other method. About two drivers each day decide not to pay and back up the ramp. Although this situation is not identical to Highway 407, we feel that this concern still applies.

Sight distances on the Highway 407 ramps were designed to the usual standards. No special consideration was given to the possibility of drivers reversing on the ramps. This may cause safety (and operational) problems.

One of the accepted principles of highway design is that designs that are in accord with driver expectation are more likely to enable drivers to respond to circumstances quickly, predictably and correctly. Conversely, uncertainty and discord with expectation makes for slow, unpredictable responses and errors. In the human factors consultant's opinion, the signing in advance of the ramps is inadequate to ensure that drivers will know what to expect, how they are going to pay, or how much. Advertising , no matter how comprehensive, will not reach all drivers.

As a result of field visits, minor concerns were expressed about some highway signs. During the field visits, the committee noted that pavement markings are now of poor quality.

6.10.1 Recommendations

- *What should be reviewed?*

1. Examine the need to repaint the pavement markings along the entire road.
2. Examine the possibility of improving signs in advance of entry to the ramps to reduce the probability of erratic manoeuvres. Also examine the options for accommodating drivers who change their minds and do not want to enter the toll road.
3. The consultant's report suggested that the following signing and markings be reviewed:

- route markers, which are small and difficult to read;
- regulatory or warning signs, some of which are small, difficult to read and situated next to directional information;
- exit signs at the gore, which should use yellow backdrop to the arrows;

- confirmation route markers and overhead signs confirming that drivers are continuing on Highway 407, the number of which should be increased;
- the airport (airplane) sign, where appropriate, which should point to the exit.

- *Considerations for the future*

Highway designers should recognize that the ergonomic (human factors) perspective and expertise should play an important role in the design process.

7. VALUE ENGINEERING OUTCOMES - HIGHWAY 407

7.1 Background In June 1993, CHIC and ORDC were qualified by MTO to participate in a competition for the right to design, construct, and operate the proposed Highway 407. Among other requirements, the two consortia were directed to examine the proposed Highway 407 toll road project in a value engineering context. MTO specified the objective, scope, services and context of the value engineering to be carried out.

The stated objective of the value engineering assignment was:

"To review the plans for Highway 407 and determine if more cost-effective designs for the facility can be developed. Where alternatives have an impact on service provided to the users of the facility, these alternatives will be evaluated against the requirements of the financing plan." (Schedule D, MTO Value Engineering Terms of Reference)

To meet that objective, the consortia were directed to review all documents provided by MTO (i.e. design reports, amendments, other documents) pertaining to the planning and design of Highway 407, and to undertake the following services:

- *"Prepare alternative plans at a conceptual level, but in sufficient detail to prove their feasibility (1:2000 scale) of any aspects of the current design that in the opinion of the consultant will produce a more cost-effective solution to satisfying the transportation needs of the Highway 407 corridor.*
  Examples to be considered are the configuration of major interchanges and ultimate cross-section of Highway 407. Staging of Highway 407 during implementation is not part of value engineering.
- *Review Ontario Provincial (OP) standards, specifications, Ministry design protocols and Highway 407 design criteria to identify alternatives that would be more cost effective in the Highway 407 application.*
- *Identify aspects of the current designs and plans that in the opinion of the consultant should be deleted and yet provide an acceptable level of service in the Highway 407/7 corridor.*
- *Identify the cost savings associated with the proposed alternative designs.*
- *Provide an evaluation, in point form, of the proposed alternative designs."* (Schedule D, MTO Value Engineering Terms of Reference)

The principal objective of the work was "to produce a more cost-effective" design with respect to the highway's configuration.

7.2 What is value engineering?

The term "value engineering" is understood to mean an economic value assessment of an engineering project. This assessment can be carried out across projects ranging from manufacturing, to structural design, to all forms of construction, to highway projects, to processes and materials used in various projects. The following definition is paraphrased from the Defence Authorization Act of the United States:

Value Engineering means an analysis of the function of a program, project, system, product, item of equipment, building, facility, service or supply, performed by qualified personnel, directed at improving performance, reliability, quality, safety and life-cycle costs.

In a highway-engineering context, we interpret this to mean that a value engineering exercise should be more than a means of identifying ways to reduce construction costs. In our view, equal attention should be given to the important attributes of performance/operation, reliability, quality and safety.

7.3 Road safety context of the work

The road safety context of the value engineering work carried out on Highway 407 was set out as follows:

"Alternative designs should not impact on the level of safety of the facility, otherwise all options will be considered by the Ministry." (Schedule D, MTO Value Engineering Terms of Reference)

If interpreted literally, this statement means that the consortia were to propose only those changes that maintained the level of safety provided by the then-prevailing design standards and safety protocols. However, MTO did not suggest how to evaluate potential changes to the level of safety that could occur due to changes in standards.

7.4 Observations on the value engineering outcomes

The main areas of change resulting from the value engineering submissions, as compared to the original MTO Highway 407 design criteria and development plan, involved two things:

1. the elimination of a number of interchanges along the highway. This proposal accounted for almost two-thirds of the economies gained through the value engineering exercise. No attempt was made in the value engineering work to explicitly quantify or qualify the safety trade-offs engendered by this change.
2. a number of changes in design and design criteria, which resulted in about one-third of the total value engineering savings. Notable among these were the substitution of inner loop ramps in place of direct connections for one four-level interchange -thereby saving one level of structures - and reductions in minimum inner loop ramp radii, which we have already discussed in this report. In no instance did we find evidence of an explicit quantitative evaluation of the safety trade-offs involved in reducing the level of design.

Changes in the level of safety resulting from reductions in design configurations and/or criteria were evaluated against the simple threshold benchmark of existing standards. If the dimension still fell above the minimum standard, it was assumed that an acceptable level of safety had been achieved. While we recognize that this approach is common in value engineering practice across North America, we have concerns with such an implicit approach to safety evaluation. Explicit and quantitative calculation of safety trade-offs is possible and desirable in all instances where design changes may result in a reduction of dimensions or safety may be comprised - whether or not the resulting change pushes the dimension below the minimum standard. Without evaluating safety - and the costs of increased or decreased accidents explicitly - it is impossible to determine if any particular change has resulted in an increase in "value" in the overall design of the road.

No examples could be found in the value engineering process where either of the consortia, or MTO, explored the opportunity for adopting cost-effective safety enhancements. This is a logical outgrowth of considering road safety only implicitly through compliance to standards; however, it does mean that opportunities for adopting such cost-effective enhancements may be lost forever. In this respect, the value engineering exercise appeared to be concerned solely with cost cutting, and was not true value engineering.

The independent engineering firm engaged to review the value engineering submissions for MTO pointed out:

"Savings from reduced design standards should be identified separately to see that the reduced safety provisions, which are inevitably the case at every compromise with design standards, are worth the savings." (FENCO. Review of Highway 407 Value Engineering, August 1993)

As a result of the value engineering exercise, the province issued an amended set of design criteria, which became the basis for the subsequent proposals by the two consortia. We found no evidence that the recommendations of the independent consultant for an explicit evaluation of costs and benefits of safety trade-offs were implemented.

7.5 Comments

1. There are no real standards for the conduct of value engineering. However, when one undertakes a value engineering exercise one may reasonably expect that where public safety is likely to be impacted by cost savings, the impact on road safety would be considered explicitly. Given this fact, both CHIC and ORDC did not explicitly account for the safety decreases that would inevitably result from some of their proposals.

   Of equal concern is the seemingly benign role played by MTO and OTCC in the pre- and post-value engineering work. In this regard, MTO is reasonably considered the guardian of safety for the travelling public. Over the past several decades, MTO staff have taken a leadership role and have often performed admirably in this regard through such activities as developing soundly based highway design standards, traffic control standards and maintenance standards.

   Unfortunately, however, in the case of the Highway 407 value engineering exercise, MTO did not insist on fully assessing the ramifications of design proposals on public safety.

2. In many instances, proposals by ORDC and CHIC, particularly where they adopted the high design standards put forth by MTO, were likely to have negligible impact on safety. In a few instances, the proposed changes did not meet the then-prevailing design standards. One could expect this to adversely affect safety. The committee notes that no one expended the effort to see whether the resulting cost savings justified the decreased safety.
3. The sole emphasis in the value engineering for Highway 407 was on cost reduction, with almost no consideration given to potentially cost-effective safety improvements.
4. The committee believes value engineering is useful if the full range of impacts, including safety, is considered. This was not the case here. The value engineering exercise for Highway 407 was largely a cost-cutting exercise.
5. An opportunity exists for MTO to ensure that all future highway work (including Highway 407) explicitly and properly accounts for safety during all activities and at each stage of the design, construct and operate sequence. From a more general perspective, future value engineering exercises must recognize safety consequences explicitly and be carried out with the help of professionals with road safety expertise.
6. Road authorities who solicit value engineering undertakings must insist that all consequences, including safety, be considered.

8. OBSERVATIONS - HOW TO BUILD SAFETY INTO A ROAD

8.1 How to build safety into a road

The process of shaping Highway 407 began nearly three decades ago. By the time the two private consortia were invited to compete for the job, the preliminary design of the highway had been completed by the MTO and some structures had been built. On this basis, the two competing consortia were asked to engage in a value engineering exercise, the purpose of which was to reduce the cost while leaving the level of safety intact. One of the two consortia, Canadian Highways International Corporation, was later engaged to produce the final detailed designs and to build the road.

The safety of the road, as it emerged from this process, has been shaped by the early decisions made by MTO, the cost-saving suggestions made by both consortia in the value engineering stage, and the decisions made during the final and detailed design. Most of these decisions were "standards driven". The predominant assumption was that if the standards were met, the needs of safety were satisfied. We have reviewed all the documentation made available to us. In all these documents we found only one issue, that of where to locate the illumination masts, on which an attempt was made to explicitly estimate the safety consequences of a design decision. Even on this issue, the eventual decision was made (between the shoulder-location and the centre-median location) as if, in either case, vehicles would never collide with the masts. Thus, in the only case where in the early analyses safety consequences were explicitly estimated, the final choice was made purely on cost. In no other decisions, whether they were about median width or shape, the need for a median barrier, the radius of an inner loop ramp, the slopes on the roadside, the length of acceleration ramps, etc., have we found written evidence that safety was explicitly examined.

The lesson of experience is always about the future, not the past. On the basis of what we learned in this review, we offer some thoughts about how the interest of safety should be served in future road building.

8.1.1 What is needed?

We asserted earlier that no road can be made completely safe, that roads can be built safer or less safe. To consciously build safety into a road requires three main ingredients:

- explicit attention to safety;
- professional know how; and
- guidance on cost versus safety.

One of the main lessons of this review is that this truth has not always been sufficiently recognized.

8.1.2 Explicit attention

Attention to safety has usually been implicit, not explicit. The assumption most frequently encountered was (and is) that if the current standards are met, the road is safe. Many of those who have made safety-related decisions for Highway 407 appear to have been under the impression that by satisfying the various standards they had automatically discharged their duty to road safety. Time and again we encountered statements testifying to the belief that safety would not be adversely affected if this or that dimension were reduced, as long as the standard was met.

In road design, standards are often no more than a limit; one must not provide less than the standard stipulates, but to provide more is usually better. Furthermore, just meeting the standard does not mean that an appropriate amount of safety has been provided. In short, implicit attention to safety by meeting design standards is insufficient.

8.1.3 Professional know how

The oft-expressed belief that as long as the standard is met safety remains unaffected seems to betray either a lack of sensitivity to the needs of safety, or insufficient awareness of extant knowledge about the relationship between the elements of the road and safety. For example, it is incompatible with the extant knowledge to maintain that obstacles farther than 10m from the edge of the travelled lane will never be hit. Nor may one legitimately assume that narrowing the median from 15m to 8.5m will not affect the frequency of accidents. Neither can one make the claim that the relationship between freeway illumination and safety is not known.

8.1.4 Cost versus safety

By far the most influential relationship that was blurred in the process by which Highway 407 was created is that between safety and cost. As in most walks of life, more money usually buys a better product. Bargains exist but they are rare. One can build a safer road if more money is spent. Conversely, saving significant amounts of money in construction will usually be reflected in more frequent or more severe accidents. This aspect of reality must be recognized and acknowledged. The citizens, the road users, and the taxpayers are not willing to spend an infinite amount of money on making roads safer. They trust their representatives to find a reasonable balance between safety and cost. It is therefore the task of the representatives to specify what the balance is to be. In the process by which Highway 407 materialized, this did not occur. Instead, the government asked that the level of safety of the original MTO design be maintained, and yet expected the two consortia to show significant cost savings.

It is difficult to show significant cost savings while maintaining the same accident frequency or severity. This favours a notion of "safety" that is divorced from its real manifestations: accident frequency and accident severity. The result is the convenient but fallacious idea that a road is "safe" if it is does not violate present-day standards. It is through the workings of this false notion that attention can be diverted from the real relationships between design decisions and safety, and attention can focus inappropriately on the question of whether standards are met. It is in this manner that the need for professional know how about the relationship between design decisions and safety consequences can be obviated.

It is possible, perhaps likely, that the role of the private sector in road building will increase. This possibility underscores the need for the guardians of public safety to proclaim the relationship between cost and safety on a realistic basis. One must recognize that savings in construction and operating costs are likely to affect accident frequencies and severities. It is the task of government to provide guidance about what trade-offs are consistent with the public interest: How much are we willing to spend to improve safety and what sacrifice in safety is not worth the attendant cost saving?

8.1.5 Fair is fair

It would be unfair to create the impression that all the elements of Highway 407 meet only minimum standards. For example, standards do not require that a road of this kind be fully illuminated, yet Highway 407's illumination is likely to be an important safety feature. Similarly, Highway 407's paved shoulders are not mandated by the standards and are likely to enhance the safety of the road.

It would be equally unfair to leave the impression that the notion "if it meets the standards it is safe" has been used only in the creation of Highway 407. The same notion has been in use from the earliest times; it is what highway designers are schooled and socialized in, and it prevails widely in highway design practice everywhere.

8.1.6 Time for change?

In the creation of Highway 407, as in the creation of all other roads, the interest of safety was maintained by adherence to design standards, warrants, guidelines and practices. In all these, safety is incorporated implicitly, often to an unknown degree. As a result of this style of highway engineering design, the level of safety that materializes is largely unpremeditated and decisions about costs are made without reference to safety consequences. If the standard is unnecessarily stringent, money is wasted; if the standard is too lax, too many or too severe accidents may ensue. In our view, the interest of public safety requires that, in the future, road design be more safety-conscious and more knowledge-based. There is a growing awareness of this need among highway design engineers. The question is how this can be accomplished.

8.1.7 How to get change

On its way from concept to contract, a road is the creation of many people. Some make safety-related decisions when the road is planned; others influence safety at the preliminary- and, later, at the detailed-design stages. When the road is being constructed, and when it is in service, many more safety-related decisions are made. All who make these decisions determine the future accident experience of the road.

We said at the outset that to build safety into a road needs (i) explicit attention to road safety, (ii) professional know how about road safety, and (iii) guidance on cost versus safety. To get explicit attention for road safety and to bring about the requisite professional know how requires actions by the government and by the profession. The government can make it plain that attention to road safety must be explicit, as it did, for example, when requiring explicit environmental assessments. The government could also make it plain that those who affect public safety through their professional decisions must be suitably trained and qualified in road safety. These issues deserve legislative attention specifying both responsibility and authority. The transportation engineering profession, in turn, must engage in all that is needed so that its members can earn and live up to this public trust.

9. CONCLUSIONS AND RECOMMENDATIONS

Highway 407 is a modern highway. By and large, it has been built to current highway geometric design standards. In some respects, those standards have been exceeded; in many cases, only minimum standards have been met. In a few instances, minimum standards have not been met. It is difficult to anticipate the safety of a highway that has not yet been used. However, in our opinion, Highway 407 is likely to have a similar level of safety as other 400 series highways in Ontario. Our review has resulted in two things. First, it has enabled us to respond to the committee's mandate. In so doing, it has also shown us that there are several measures that have the potential of enhancing the safety of Highway 407. We suggest that these measures be examined in detail immediately. Second, there is the broad issue of how to build an appropriate amount of safety into roads. The committee is concerned that present practice deals with road safety only implicitly, without using all available knowledge and without extracting the safety lessons from accumulated professional experience. We have included recommendations dealing with the procedures that should help build into roads the appropriate amount of safety. We suggest that public road administrations, such as the Ministry of Transportation, and the community of transportation design professionals examine this broad issue with respect to their own roles and responsibilities in providing safe and efficient streets and highways.

9.1 Responding to the mandate

- *The Committee will undertake an independent safety review to address whether appropriate engineering standards were used in the design of Highway 407. This would include a review of the design issues raised by the Provincial Auditor and the Ontario Provincial Police (OPP)*. [Committee Mandate, Section 1.5]

MTO's geometric design standards are comparable to those used elsewhere in North America. Highway 407's safety design was based on the premise that if the current geometric design standards were maintained, the highway would have the accepted level of safety as set out by MTO. Although the committee questions this approach, we acknowledge that this, too, is common practice within the highway engineering profession. Highway 407 mostly met or exceeded the MTO design standards. The Provincial Auditor suggested that the value engineering process should be applied to other provincial highways. The committee agrees with this suggestion, however the value engineering process for Highway 407 was no more than a cost-cutting exercise. Future value engineering exercises should consider all the needs of road users, including safety. Safety needs must be explicitly evaluated in a manner similar to financial and environmental issues, and not simply for compliance to standards. The particular issues raised by the OPP were:

- protection for the median high-mast lighting;
- the median bridge piers;
- the sediment control and drainage devices in the median; and
- the radii used on some of the inner loop ramps at interchanges.

The committee examined these issues and agrees with these concerns, which are discussed in Chapter 6. The committee did not agree with the OPP proposal for a median barrier.

- *The Committee will also address the appropriateness of the outcomes of the value engineering exercise on the design of Highway 407*. [Committee Mandate Section 1.5]

The value engineering process allowed for a reduction in the cost to build the first phase of Highway 407, as directed by the government. Implicit in the two value engineering studies is the assumption that if the current standards were met, the required level of safety would be maintained. Although the committee questions this approach, we acknowledge that this, too, seems to be common practice. The outcome of the value engineering process generated development alternatives. However, the failure to follow up on the recommendation in FENCO's independent assessment of the value engineering submissions, that safety trade-offs resulting from any reduction in standards should be evaluated through an explicit cost/benefit analysis, may have resulted in some of the features of the new highway being different from what they might otherwise have been.

- *Determine whether the highway meets or exceeds Ontario standards which have a bearing on road safety*. [Committee Mandate, Section 1.5]

The geometric design features of Highway 407 reviewed by the committee mostly met or exceeded the MTO geometric design standards, except at the locations noted in the report. We also note that in some instances, while the letter of the standard has been met, its spirit has not been.

- *Determine whether the standards used and the design decisions taken in the design of the highway were applied in a manner which appropriately addressed safety*. [Committee Mandate, Section 1.5]

The design of Highway 407 was based on the premise that if the current geometric design standards were met, the highway would have the accepted level of safety, as set out by MTO. Although the committee questions this approach, we acknowledge that this is common practice within the highway engineering profession. There was only one documented case of an explicit safety evaluation of any feature of the highway and that was the question of where to locate the lighting masts.

- *Determine if cost-effective opportunities were taken to enhance the highway's safety*. [Committee Mandate, Section 1.5]

It is the committee's view that the highway's safety was enhanced by the following features: illumination throughout, a median in excess of 22m, and paved shoulders. In various places in the report, we note that while opportunities to enhance safety existed during the design process, the committee has no documents to show that they were examined. These opportunities pertain to design decisions about the width of the median and its cross-section, protection of the lighting masts, the fill and cut slopes, the length of barriers, substitution of directional ramps by loop ramps, and the like. The committee did not have the time to determine the cost effectiveness of these opportunities.

- *Consider whether there are seemingly cost-effective opportunities to enhance the safety of the highway which merit consideration by the Ministry of Transportation*. [Committee Mandate, Section 1.5]

The committee did not have the time to identify all the promising courses of action and to analyze which of these, if any, are cost-effective. Based on our collective judgment, we recommend that, among other ways to reduce the frequency and severity of collisions, the following options be considered:

- installation of inertial devices (crash cushions) around each high-mast lighting pole;
- installation of crash protection for the median bridge piers;
- reshaping of the median cross-section to be more forgiving_with special attention to the V-ditch in the centre of the median;
- installation of rumble strips on the median shoulder and possibly on the right shoulder of the highway;
- reshaping of some hydraulic structures to be more forgiving;
- extension of barriers, especially on ramps;
- flattening of slopes where feasible;
- improvement of information signing and other provisions of the toll collection system to reduce the possibility of dangerous manoeuvres by drivers balking before the toll gantry;
- additional positive guidance at tighter loop ramps;
- measures to increase ramp surface friction; and
- repainting of faded pavement markings on the mainline.

9.2 What should be done to build the right amount of safety into roads ?

The benefits of mobility are bought at a cost. The cost of mobility is not only a monetary one; but it also relates to noise, air pollution, frustration, expenditure of time and the cost of collisions, which include loss of life, personal injuries and property damage. Collisions are one of the costs of mobility. The frequency and severity of collisions is not unchangeable; it is subject to management by a variety of means. Some tools of safety management are oriented toward the driver, some toward the vehicle, and some toward the road and its environment. In our opinion, the management of road safety by engineering design and operations requires rethinking. This has implications for the highway engineering design profession, as well as for government and other agencies responsible for "delivering" road systems to the public. We say this for three reasons.

1. Present practice in highway design is less than satisfactory. Details of what is not satisfactory are provided in the body of this report and do not bear repeating. In sum, we think that those who make decisions that materially affect road safety must do so on the basis of available factual knowledge. Just "designing to standards" is not thoughtful engineering and is inadequate, particularly regarding road safety. Yet it is evident that this represents the state of highway engineering design in many North American highway agencies today. Accordingly, we recommend that the government and professional associations examine the implications of current highway design practice with a view to ensuring that road safety is considered in an appropriate and explicit manner during the road design process.
2. Road safety failures are not always obvious. If a bridge collapses or a basement leaks, the failure is manifest. Not so in road safety. A road safety shortcoming is a matter of degree and may become manifest only through a long history of collisions. For this reason, it usually remains unrecognized and unmitigated. Furthermore, the owner of the deficient bridge or basement will tend to seek redress, and those responsible for the failure will learn from their mistakes. None of this works well in road safety engineering. In addition, the traditional role of government in designing, building and operating roads is changing. We expect that more of the engineering will be done outside the civil service. We also expect that there will be more projects of the design-build kind. For these reasons, it is evident that building an appropriate amount of safety into roads requires a "guardian". The committee believes that the Ministry of Transportation is a sensible

choice for guarding the interests of the public in road safety. Accordingly, we recommend that the Minister of Transportation examine the broad spectrum of issues, including those of responsibility and authority, relating to the question of how to ensure that an appropriate amount of safety is built into a road.

3. It is evident from our discussions with the OPP and MTO that an opportunity exists for a cooperative sharing of information and experience. The OPP and MTO have valuable experience and important information, some of which is shared (e.g. the accident report form that is filled out for reportable motor vehicle accidents) and some of which is not shared (e.g. that which comes out of detailed accident reconstructions by the police). Similarly, there are analyses completed by MTO that would be useful to the OPP. Our impression is that there are currently inadequate institutional arrangements to facilitate the flow of information for the mutual enrichment of the police and the transportation professionals who design and operate roads. Accordingly, we recommend to the Minister of Transportation and to the Solicitor General of Ontario that steps be taken to enhance the cooperative sharing of road safety information and experience between MTO and the OPP.

10. COMMITTEE SIGN-OFF

Readers of the attached report should note that, in preparing the report, the committee worked within time limitations, which necessarily limited the scope of the committee's investigation to some degree. Nonetheless, the members of the committee are confident that the report appropriately addresses the significant design and safety issues relative to Highway 407.

The committee believes that the report contains a reasonably thorough analysis of all of the major elements of the Highway 407 design and many of the relatively minor elements of that design. Since it was impossible for us to review every detail of the highway design within the time available, in some instances we reviewed representative samples of the design to develop an understanding as to the overall approach.

Our work focused mainly on the plans and documentation made available to us and we assume that such plans and documentation as provided by OTCC, CHIC, MTO and others were complete and accurate. Again, owing to time limitations, we did not undertake comprehensive field evaluations or exhaustive file confirmations; rather, we did limited field evaluation to confirm certain elements observed in the design.

Notwithstanding the limitations described above, we are confident that our approach to this review was reasonable and that there is a sound basis for our observations.

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Signature ______ Date 25 MAR/97

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APPENDIX A. GLOSSARY

- **Acceleration lane**
  A lane in addition and adjacent to a through lane to enable a vehicle entering a roadway to increase speed to merge with through traffic. Used at intersections where traffic is channeled by means of islands or markings, or as a speed-change lane at interchanges.
- **Assumed speed**
  The speed assumed for calculating the minimum distance needed for a driver to stop safely for an obstacle that has just come into view.
- **Average daily traffic (ADT)**
  The total volume of traffic during a given time period, in whole days greater than one day and less than one year, divided by the number of days in the period.
- **Average annual daily traffic (AADT)**
  The average 24-hour, two-way traffic for the period January 1 to December 31.
- **Auxiliary lane**
  A lane in addition and adjacent to a through lane intended for a specific manoeuvre, such as turning, merging, diverging, weaving, and for slow vehicles, but not for parking.
- **Back slope**
  The slope between the drainage channel and the natural ground, used when a roadway is below natural elevation.
- **Barrier**
  A device providing a physical limitation through which a vehicle would not normally pass. It is intended to contain or redirect errant vehicles of a particular size range, at a given speed and angle of impact.
- **Breakaway**
  A design feature enabling such devices as signs, luminaires or traffic signal supports to yield or separate upon impact. The release mechanism may be a slip plan, plastic hinges, fracture elements, or a combination of these.
- **Braking distance**
  The distance travelled from the instant that braking begins to the instant a vehicle comes to a stop.
- **Bullnose**
  The location where the edge of a highway and the edge of a ramp meet. It may or may not include the curb and the gutter.
- **Clear zone**
  The total roadside border area clear of obstacles, starting at the edge of the travelled way, available for safe use by errant vehicles. This area may consist of a shoulder, a recoverable slope and/or a clear run-out area. The desired width depends on traffic volumes and speed, and on roadside geometry.
- **Cost effective**
  An item or action that is economical in terms of tangible benefits produced by money spent.
- **Crash cushion**
  An impact-attenuating device that brings an errant vehicle to a safe stop or redirects it, to prevent the vehicle from colliding with fixed-object hazards by gradually decelerating the vehicle away from the hazard.
- **Crashworthy**
  A feature that has been proved acceptable for use under specified conditions, through crash testing or in-service performance.
- **Crest vertical curve**
  A vertical curve having a convex shape in profile viewed from the side.
- **Cross-section**
  The transverse profile of a road.
- **Cross fall (cross slope)**
  The average grade between edges of a cross-section element.
- **Crown**
  The highest point of the surface of a roadway in the cross-section view.
- **Curvilinear alignment**
  The configuration of a section of road, as seen in a plan, that is mostly a circular and spiral curve.
- **Cut**
  A roadway that is located below natural ground elevation is said to be in cut.
- **Cut side slope** The slope between a roadway and a drainage channel, when the roadway is below natural ground elevation.

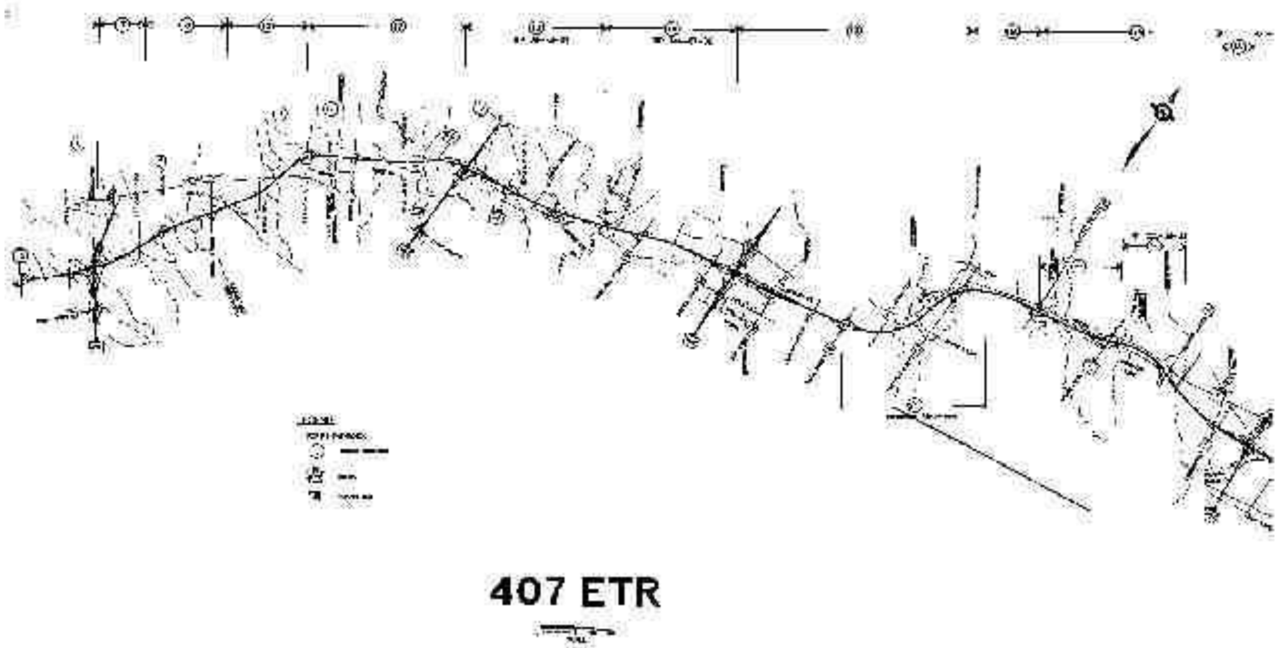
- **Deceleration lane**
  A lane in addition and adjacent to the through lane to enable a vehicle exiting a roadway to reduce speed after it has left the through traffic lanes. Used at intersections where traffic is channeled by islands or markings, or as a speed-change lane at interchanges.
- **Decision sight distance**
  The distance required for a driver to detect an information source or hazard in a visually cluttered roadway environment, recognize the hazard or its potential threat, select appropriate action, and complete the manoeuvre safely and efficiently.
- **Design criteria**
  A set of parameters established at the outset of the design phase for the major elements of a facility, to provide direction for the designers.
- **Design speed** A speed selected for designing and correlating the geometric features of a road, and used as a measure of the quality of the road's design.
- **Design hour volume (DHV)**
  Volume of traffic in the design hour.
- **Drainage channel**
  A channel placed adjacent to a roadway's outside lane or shoulder, intended to control and conduct storm-water that runs off the roadway and adjacent slopes. A shallow drainage channel is sometimes referred to as a swale.
- **Drainage features**
  Roadside items, such as curbs, culverts, ditches and drop inlets, whose primary purpose is to provide adequate roadway drainage.
- **End treatment**
  The design modification of a roadside or median barrier at the end of the installation.
- **Entrance**
  The general area where traffic turns to enter the main roadway.
- **Entrance terminal**
  The acceleration or speed-change lanes that are part of a roadway entrance, including the ramp proper up to the ramp controlling curve.
- **Exit**
  The general area where traffic departs from the main roadway.
- **Exit terminal**
  The deceleration or speed-change lanes that are part of a roadway exit, including the ramp proper up to the ramp controlling curve.
- **Fill**
  A roadway located above the natural ground elevation is said to be in fill.
- **Fill side slope**
  The slope between the roadway and the natural ground, where the roadway is located above the natural ground elevation. Sometimes called the fill slope.
- **Freeway**
  A road limited to through traffic, with access through interchanges.
- **Friction factor**
  The ratio of the frictional force with which the tire and roadway press against each other, measured either in line with the roadway or sideways to it.
- **Geometric design**
  Selection of the visible dimensions of a roadway's elements.
- **Gore area**
  Area between the edge of a highway, the edge of a ramp and the place where the ramp and highway meet.
- **Gradient (Grade)**
  How fast elevation changes relative to a horizontal distance (steepness), usually expressed as a percentage.
- **Guiderail (Guardrail)**
  A barrier adjacent to and in line with the roadway, which can be made of concrete, steel beam, or post and rail.
- **Hazard**
  Any obstacle or other feature, such as an embankment or a body of water deeper than 1m, which, without protection, is likely to cause significant injury to the occupants of a vehicle encountering it.

- **Horizontal alignment**
  The configuration of a road, as seen in a plan, consisting of straight lines, lengths of circular curve, and lengths of spiral or transition curves.
- **Horizontal curve**
  A circular curve, as seen in a plan, that enables a driver to change direction.
- **Impact attenuator**
  See crash cushion.
- **Interchange**
  The general area where two or more through roads of different elevations cross or join, with one or more turning roadways for travel between the through roads.
- **Intersection (at-grade)**
  The general area where two or more roads join or cross, within which are included the roadway and roadside facilities for traffic movements.
- **Lane (Traffic lane)**
  A part of the travelled roadway intended for the movement of a single line of vehicles.
- **Length of need**
  The total length of a barrier in line with the roadway needed to shield a hazard.
- **Median**
  The area that separates traffic lanes carrying traffic in opposite directions. A median is described as flush, raised or depressed, referring to its general elevation relative to the adjacent edges of traffic lanes. The terms wide and narrow are often used to distinguish different types of median. A wide median generally refers to depressed medians sufficiently wide to form a channel that drains a roadway's base or sub-base. Flush and raised medians are usually narrow medians.
- **Median barrier**
  A barrier in line with the roadway placed in the median to prevent a vehicle from crossing the median and encountering oncoming traffic, or to protect a vehicle from hitting a fixed object in the median.
- **Minimum stopping sight distance**
  The minimum distance a driver who sees an object ahead requires to come to a stop under prevailing vehicle, pavement and climatic conditions.
- **Non-recoverable slope**
  A slope that is considered traversable, but on which errant vehicles will continue to the bottom with little chance for recovery. Embankment slopes between 4:1 and 3:1 may be considered traversable but non-recoverable, if they are smooth and free of fixed-object hazards.
- **Obstacle**
  Any fixed object that is likely to cause significant injury to occupants of a vehicle hitting it.
- **Offset**
  The distance between the travelled way and a roadside barrier or other obstacle.
- **Operating speed**
  The speed on a section of highway below which 85% of drivers are operating vehicles when there is little traffic and good weather. This speed may be higher or lower than posted or legislated speed limits, or nominal design speeds, where alignment, surface, roadside development or other features affect vehicle operations.
- **Overpass**
  An elevated road passing over an intersecting road or railway.
- **Perception time**
  The time between when a driver observes an object for which it is necessary to stop and when the driver decides to take remedial action.
- **Ramp**
  A turning roadway that enables traffic to move from one highway to another.
- **Recoverable slope**
  A slope on which drivers may, to a greater or lesser extent, retain or regain control of a vehicle. Slopes 4:1 or flatter are generally considered recoverable.
- **Recovery area**
  Generally synonymous with clear zone.
- **Right-of-way**
  The land acquired to provide a road.
- **Rigid barrier**
  A barrier adjacent to and in line with a roadway that is intended to redirect an errant vehicle with minimum deflection in itself, usually a continuous concrete mass.

- **Road**
  All the land acquired to provide a common or public thoroughfare, including a highway, street, bridge and any other structure incidental thereto.
- **Roadside**
  The area between the outside shoulder edge and the right-of-way limits.
- **Roadside barrier**
  A barrier in line with the roadway placed adjacent to the right or left edge, to prevent a vehicle leaving the roadway from encountering a hazard.
- **Roadway**
  That part of a road on which vehicles drive, inclusive of the shoulder.
- **Rounding**
  The introduction of a smooth transition between two transverse slopes to minimize the abrupt slope change and to enable a vehicle to traverse such slopes without bottoming out or vaulting
- **Runout length**
  A distance parallel to the roadway, measured from an object to the point at which a vehicle leaves the roadway. This distance varies with design speed and traffic volume.
- **Sag vertical curve**
  The bottom of a hill, viewed from the side.
- **Semi-rigid barrier**
  A barrier adjacent to and in line with a roadway that is intended to redirect an errant vehicle by a system of steel beams attached to posts.
- **Shielding**
  The introduction of a barrier or crash cushion between a vehicle and an obstacle, or area of concern, to reduce the severity of impacts of errant vehicles.
- **Shoulder**
  An area of pavement, gravel or hard surface placed adjacent to through or auxiliary lanes. Intended for emergency stopping and travel by emergency vehicles only, it also provides structural support for the pavement.
- **Slope**
  The relative steepness of the terrain expressed as a ratio or percentage change. Slopes may be categorized as positive (back slopes) or negative (fore slopes), and as parallel or cross slopes relative to the traffic direction.
- **Speed-change lane**
  A deceleration or acceleration lane.
- **Stopping distance**
  The distance a vehicle travels from when a driver decides to take remedial action to when the vehicle stops (total of reaction and braking distances).
- S**topping sight distance**
  The distance between a vehicle and an object for which a driver decides to stop, measured from where the object first comes into view (total of perception reaction and braking distances).
- **Superelevation**
  The change in elevation across a roadway from the inside to the outside edge of a curve measured at right angles to the centre line.
- **Through lane**
  A lane intended for through traffic movement.
- **Traffic barrier**
  Traffic barriers are placed adjacent to and in line with a roadway to protect traffic on the roadway from hazardous objects either fixed or moving (other traffic). Barriers placed in a median are referred to as median barriers and may be placed in flush, raised or depressed medians.
- **Transition (spiral) curve**
  A curve whose radius continuously changes.
- **Underpass**
  A road that passes under a highway or railway.
- **Vertical alignment**
  The configuration of a road or roadway as seen in longitudinal section, consisting of tangents and parabolic curves.
- **Vertical curvature (K)**
  The horizontal distance along a hill required to effect a 1% change in elevation.

- **Vertical curve**
  A parabolic curve on the longitudinal profile or in a vertical plane of a road to provide for a change of gradient.
- **Warrant**
  The criteria by which the need for a safety treatment or improvement can be determined.
- **Weaving section**
  A section of roadway between an entrance and an exit, where the frequency of lane changing exceeds the frequency on the open highway.

APPENDIX B. KEY PLAN OF REVIEW PORTION OF HIGHWAY 407



APPENDIX C. BIOGRAPHIES OF PEO HIGHWAY 407 SAFETY REVIEW COMMITTEE

John Robinson, Ph.D., P.Eng. (Chair)

Dr. Robinson is a Senior Associate, Transportation, with UMA Engineering Ltd. Active in the transportation engineering field since 1969, his expertise includes involvement in a wide variety of transportation projects ranging from highway design and traffic engineering to transportation systems planning, pavement management, and intelligent transportation systems.

Brian Allen, Ph.D., P.Eng.

Dr. Allen is an Associate Professor at McMaster University in Hamilton, Ontario, as well as President of AT Traffic Safety Corporation. Dr. Allen has taught both undergraduate and graduate courses in highway design, traffic engineering and traffic safety in the Department of Civil Engineering at McMaster University since 1972. AT Traffic Safety Corporation is a company that conducts road safety studies, accident reconstruction, real-time 3-D animation, and safety research.

Ezra Hauer, Ph.D., P.Eng.

Dr. Hauer is a Professor, Department of Civil Engineering, at the University of Toronto. Extensively published, and recognized world-wide, Dr. Hauer has been active in road safety research and consulting since 1970.

Frank Navin, Ph.D., P.Eng.

Dr. Navin is President of Hamilton Associates of Vancouver, British Columbia, and since 1972 a Professor of Civil Engineering at The University of British Columbia. He has worked in the field of transportation planning since 1968, and from1979 has been the coordinator of Transport Canada Accident Research Team at UBC and experimental road safety research.

Arthur Scott, P.Eng.

Mr. Scott is a transportation consulting engineer with extensive experience in the design of a wide range of highway and road projects, with emphasis on freeways and rural highways. During his career, he has worked on more than 70 transportation engineering projects in Ontario and elsewhere in the world with Canadian-based Delcan Corporation and U.S.-based De Leuw Cather and Co., among others.

Gerry Smith, P.Eng.

Mr. Smith is the Director of Transportation for the UMA Group. Mr. Smith has been with UMA for 34 years and is currently responsible for providing technical and

APPENDIX D. LIST OF DOCUMENTS PROVIDED TO THE REVIEW COMMITTEE

1. Ministry of Transportation (MTO). File A10-005 - *Value Engineering Proposals and Related Studies; Geometric Design Standards for Ontario Highways;* Highway 407 Project.
2. Canadian Highways International Corporation (CHIC). 407 Next Exit Phase One Part 1- Value Engineering Highway 407 Toll Road; Four memos and attachments: Highway 407 Design Criteria, Delcan.
3. MTO. File 110-008 - Request for Proposal-Highway 407 from 403 to Highway 48 as Toll Highway; *Value Engineering Proposal and Related Studies*.
4. MTO. 2 file folders - Design Criteria, March 1994, February 1992.
5. MTO. *Review of Highway 407 Value Engineering*; Memo and attachment: Design Criteria-Crown Design, FENCO/MacLaren, August 1993.
6. Figures A1, B1, C1, D1 - Technical Paper 2.6; 407/410 Interchange Complex, Figure B1.
7. Modification Drawing 1 of 3, 2 of 3, 3 of 3 - 407/410 Interchange plan & profile modification drawing.
8. MTO. *407 ETR*, January 1997.
9. MTO. Book 1 - Segments 6, 7A, 7B, 8, 8B, 9, 10, 11, 12.
10. MTO. Book 2 - Segment 14B; Segment 14B Struct.; Segment 15 & 17; Segment 15 Struct.; Contract 94-37 Electric; Contract 94-37A.
11. MTO. Book 3 - Segments 18, 13.
12. MTO. Package 7 - 407 from Station 21+825 to 22-100; Sheets 7-10, 23-24.
13. MTO. Package 18 - all sheets including index.
14. MTO. 94-37A Sheet 27, part B; Sheet Index (Sheet 364); copy of the key plan; Index and Part A-Sheet Index (Sheet 9).
15. Hamilton Associates. *Safety Barriers for Roads and Bridges* (from Australia), May 1996.
16. MTO. Segment 13: Jane Street to Centre Street.
17. MTO. Drawing sheets 47B, 88A; Quality sheet 166B.
18. MTO. Crown contract - Contract No. 90-60: Sheets 10B, 9B, 8A, 11B, 14A, 22A, 23A, 30A.
19. MTO. Crown contract - Contract No. 90-18: Sheets 48A, 49A, 50A, 62A, 63, 64, 64B, 65B, 9A, 10A, 11A, 12A, 28A, 29A, 13A, 41A, 41-1, 51A, 52A, 64A, 65A.
20. Hamilton Associates, *Highway Standards Review*.
21. MTO. Crown contract - No. 93-100: Sheets: 165A, 166A, 167A.
22. MTO. Crown contract - No. 93-93: Sheets 105A, 106A, 117A, 118A, 119A, 120A, 152A, 153A, 154A.
23. MTO. Crown contract - No. 93-44: Sheets 199A, 200A, 201, 202A, 233A, 234A.
24. MTO. Crown contract - No. 93-86: Book 1 of 2 (3 copies).
25. MTO. Crown contract - No. 89-65.
26. MTO. Crown contract - No. 92-86: Book 2 of 2 (3 copies).
27. MTO. Crown contract - No. 92-40: Books 1 of 2 and 2 of 2.
28. MTO. Crown contract - No. 92-66: Book 2 of 2.
29. MTO. Crown contract - No. 89-62: Books 1 of 2 and 2 of 2.
30. MTO. Crown contract - Highway 407/Contract No. 89-62: WP 88-78-07 Revision 1990.
31. Hamilton Associates. *Road Safety Audits in British Columbia*.
32. MTO. Crown contract - No. 94-36: Structure at the CN Macmillan Yard.
33. MTO. *Geometric Design Standards for Ontario Highways*.
34. MTO. *Roadside Safety Manual*.
35. MTO. *Manual of Uniform Traffic Control Devices*.
36. MTO. *Electrical Engineering Manual-Volume 1*.
37. MTO. *Ontario Provincial Standards: Volume 1-Standard Specifications, Volume 2-Specifications for Material, Volume 3-Standard Drawings*.
38. MTO. *Contract Design, Estimating and Documentation Manual: Volume 2* (includes standard special provisions).
39. MTO. Highway 407 from Jane Street easterly 9.5 miles to Woodbine Ave. and new Highway 7 from West of Dufferin Street easterly 4.0 miles to Bayview Avenue: W.P. 89-78-00 District 6, Preliminary Design Report (Environmental Status Statement, Volume 1, Volume 2 and Volume 3).
40. MTO, File No 93-86/E40-15 - 407 Contract.
41. MTO. File No. 93-100/E40-17 - 407 Contact.
42. MTO. File No. 90-60 E40-9 - 400/407 interchange.
43. MTO. *Report on Intersection Illumination*, February 1975.
44. MTO. File No. 93-102 E40-18.
45. MTO. File No. 90-18E40-8 - At Hwy407-400.
46. MTO. File No. 92-66E40-12 - Hwy 400 from Steeles Avenue to Hwy 407.
47. MTO. File No. 89-62E40-6 - Hwy 427, 27 & 407.
48. MTO. File 92-40_407 from Humber River to Pine Valley Drive.

49. MTO. File A40-20-003 - *Luminaire Selection Study for Highway 407 Lighting based on glare control criteria*, parts A and B.
50. MTO. File A40-20-002 - *High Mast Lighting System; Computer Report*.
51. MTO. File A40-20-04 - *Development of Glare Criteria for High Mast Lighting*, SNC Lavalin, March 1992
52. MTO. File 93-102/E40-18.
53. MTO. File TRR 1280 - *Methodology for Estimating Safe Operating Speeds for Heavy Trucks and Combination Vehicles on Interchange Ramps*.
54. MTO, File 92-66/E40-12 - Highway 400 from Steeles Avenue to Highway 7.
55. Hamilton Associates. *Review of Traffic Operations along the Willingdon/Grandview Weave Sections of Highway 1*, January 1997.
56. MTO. File 98-65/E40-7 - Weston Road & 407 Structure.
57. MTO. *Highway 401 Median Related Collision Analysis, Quebec/Ontario Border to Durham Regional Boundary*, Eastern Region Traffic Section, Kingson, Bob Boutilier, Paul Whiteman, April 1995.
58. American Automobile Association Foundation for Traffic Safety; Institute of Transportation Studies; University of California, Irvine. *The Impact of Jersey Median Barriers on the Frequency and Severity of Freeway Accidents*, M.G. McNally, Ph.D., Omar Merheb, November 1991.
59. MTO. File 93-72/E40-21 - Tender Opening No. 16, July 1993.
60. MTO. File 93-93/E40-22 - Tender Opening No. 23, September 8, 1993.
61. MTO. File 93-44/E40-20 - Tender Opening No. 24, September 15, 1993.
62. CHIC/Ontario Road Development Corporation. File A10-1-21 - Legal Agreement with CHIC Value Engineering.
63. CHIC. File - Approved Design Criteria Segment 1-4.
64. Ontario Transportation Capital Corporation (OTCC), File B.2 - Amendment to MTO Supplemental General Conditions of Contract April 1992. Special Provisions No. 109F02.
65. OTCC. File B.3 - Project Package 29-Highway 407/Keele Street underpass Site 37-13992 (Final Submission).
66. OTCC. File B.04 - CHIC Highway 407 Toll Road: Structure No. E15: Bathurst Street over Highway 407.
67. OTCC. File B.05 - Structure E31: Leslie Street over 407; Structure No. C18-Right Exit: Highway 401 Culvert at Sta. 8+791.7.
68. OTCC. File B.12 - Advanced Culverts (C8, C8A, C12, C25, C50, C50A, D8, E3, E6, E9, E10).
69. OTCC. File B.14 - Highway 404/407 Interchange: Trunk Storm Drainage System, M.M. Dillon.
70. OTCC. File B.15 - Segment No. 9: Structure No. D01: Highway 407 Steeles Avenue underpass (substructure) Grading Quantities,Giffels Associates Ltd., January 27, 1995.
71. OTCC. File B.17 - Highway 407 Toll Road Structure No. E23A: Highway 7N over Ramp 407 E-Yonge NS, Proctor & Redfern.
72. OTCC. File B.18 - Design Synopsis: Segment No. 7: Toll Highway 407 from West of Tomken Road C401-007-470-22-9002.
73. OTCC. File B.20 - Highway 404/407 Interchange: Segment 15 and 17 Substructure Contract.
74. OTCC. File B.21 - Segment No. 6: Structure No. C09 Highway 407 Ramp 407 E-401S over Highways 407 and 410, Giffels Associates Ltd., February 10, 1995.
75. OTCC. File B.22 - Design Synopsis: Segment No. 12 - Toll Highway 407 Airport Road to Highway 27 9401 012-520-22-9003.
76. OTCC. File B.25 - Segment No. 13: Toll Highway 407 Centre Street to Dufferin Street Sta. 24+695 to Sta. 26+060; Design Synopsis: 94-1-13-530-22-9038-00.
77. OTCC. File B.26 - Segment No. 14B: Toll Highway 407 Bathurst Street to German Mill Creek Sta. 28+700 to Sta. 12+400; Design Synopsis: 9401-14B600-22-9115.
78. OTCC. File B.27 - Segment No. 14B: Highway 407 Westbound lane and Eastbound lane over CNR BALA: Site 37-1453/1&2 Structures E24 and E25.
79. OTCC. File B.28 - 404/407 Interchange: Segments 15 and 17-Substructure: Contract E36 and E37, M.M. Dillon.
80. CHIC. File B.33 - Bramalea Road interchange.
81. CHIC. File B.52 - Highway 404/407 Interchange: Segments 15 & 17-Rough Grading Contract.
82. CHIC. File B.56 - Highway 407 Toll Road: CPSS Spec. S.P. Summary, Structure No. E62: Highway 407 EBL over Cedar Avenue.
83. CHIC. File B.57 - Highway 407: CNR Halton to Airport Road, Totten Sims Hubicki Associates Ltd., June 1995; Segment No. 10: Ref. 9401-20.10.22.1 Component 500.
84. CHIC. File B.60 - Ramp 407E, W-404N over Ramp 404S-7E,W; Site 37-1459: Structure E46; Tender item/S.P. Summary.
85. CHIC. File B.65 - Segment No. 8 Toll Highway 407: Dixie Road Interchange-9401-8-480-22-9216-00 Design Synopsis, Proctor & Redfern, June 1995.
86. CHIC. File B.66 - Segment No. 5: Structure No. C97. Highway 407-Highway 407 WBL over Highway 410 and Ramp N-E & S-W, Tender Documentation, Giffels Associates Ltd., April 1995.

87. CHIC. File B.71 - Segment No. 5: Structure No. C08-Highway 407: Ramp 407W-410N over Highway S407 & 410 (substructure), Tender Documentation, Giffels Associates Ltd., May 1995.
88. CHIC. File B.83 - Toll Highway 407: Ramp 404S-407W over Highway 404 and 407 Structure No. E36 specifications, Doc. No. 9401-17-249-25-9001 Rev:000, M.M. Dillon, June 1995.
89. CHIC. File B.83 - Ramp 404N-407E Structure over Highways 404 & 407 (Str. No. 37), M.M. Dillon, June 1995.
90. CHIC. File B.87 - Airport Road to Highway 27.
91. CHIC. File B.88 - Highway 401 to Tomken Road.
92. CHIC. File B.100 - Highway 404/407 Interchange: Segments 15&17 final grading and paving contract, M.M. Dillon.
93. CHIC. File B.113 - CN Newmarket Rec. Aug. 30, 1995, 94-1-12-200-23-9006, Specifications and standards (Superstructure).
94. CHIC. Annex A - Supporting information, Volume 1.
95. CHIC. Annex B1 - Engineering drawings.
96. CHIC. Annex B2 - Engineering Drawings, Volume 1; Organization Development and Operational Plan, Volume 1.
97. MTO. File A01-011 - Provincial Manuals & Min. Directives: *Roadside Safety Manual*.
98. MTO. File A01-007 - *Traffic Control Devices; King's Highway Guide Signing Policy Manual*; Provincial Manuals & Ministry Directives.
99. MTO. File A01-01-001 - Contract Design-Estimating and Documentation, Volume 1.
100. MTO. File A01-01-006 - *Electrical Engineering Manual, Volume 1; Ontario Provincial Standard Specifications, Volume 1-Construction*.
101. MTO. File A01-01-008 - *Ontario Provincial Standards for Roads and Municipalities, Volume 2-Specifications for Material; Ontario Standard for Roads & Municipal Safety, Volume 3-Drainage Sanitary Sewers, Watermains and Structures*.
102. MTO. File E20-4 - Highway 407 from W of Airport Road easterly 10.2 miles to Jane St., Highway 427 N of Finch 2.7 miles to Highway 7, Highway 400 S to Steeles N by 2.4 miles N to Highway 7, Volumes 1-4
103. U.S. Department of Transportation, Federal Highway Administration. TRR 1385 - *Accidents and Safety Associated with Interchanges*, J.M. Twomey, M.L. Heckman, J.C. Hayward and R.J. Zuk, (six-page document).
104. U.S. Department of Transportation, Federal Highway Administration. State of the Art Report 6 - *Effect of Alignment on Highway Safety*, J.C. Glennon, (15 pages); *Collision Characteristics for Central Region Freeways: Grass Median Sections* (four pages), 1991-1993.
105. MTO. *Highway 401 Median Barrier Planning Report: Hwys. 35/115 IC (Newcastle) to Hwy. 33 (Trenton) 88.4km*, L. Politano, P.Eng., E. Ellard, P.Eng., A. Wittenberg, P.Eng., June 1993.
106. Hamilton Associates. *Trans Canada Highway Construction Zone Traffic Impacts-Phase 1: Development of Traffic Control Options*, S.R. Zein, M.Eng., P.Eng., B.A. Locher, P.Eng., LL.B., September 1996.
107. Hamilton Associates. *Discussion Document* (13-page document).
108. MTO. *Inner Loop Ramp Radius Study*, R.W. Oddson, March 1990.
109. MTO. *Central Region Collision Analysis Report 1991-1993*.
110. MTO. *Highway 401 Accident Analysis, London to Woodstock*, August 1995.
111. MTO. *Traffic Operations Study: Highway 403, QEW to Highway 6*, October 1993.
112. MTO. Highway 401 Windsor to Cambridge, July 1993.
113. MTO. *Median Barrier Planning Report: Highway 401*, June 1993.
114. MTO. *Highway 401 Woodstock to Kitchener Accident Analysis*, April 1993.
115. MTO. *Box Beam Barrier Performance: An Operational Review*, March 1993.
116. MTO. *Highway 401 Windsor to Guelph, Southwest Region Accident Analysis Report*, September 1992.
117. MTO. *Conestoga Parkway Accident Analysis*, June 1992.
118. MTO. *Concrete Barrier: Performance at Different Offsets*, May 1987.
119. MTO. *Concrete Barrier Performance and Lane of Origin Distribution*, May 1987.
120. MTO. *Barrier Performance Study*, February 1987.
121. MTO. *Highway 401 Median Related Collision Analysis, Quebec Border to Durham Region*, April 1985.
122. MTO. Proposed Median Barrier: Highway 401 Mississauga, January 1974.
123. MTO. *Median Control on the Ottawa Queensway*-1973.
124. MTO. *Performance of Median Barrier Systems*, April 1973.
125. MTO. *Unlit Freeways No Bargain, Motorists Learn*, [external document], 1985.
126. MTO. *Safety on the Road at Night* [external document], 1976.
127. MTO. *Comparison of Similar Ramps at Existing Interchanges, 1989-1993*.
128. MTO. Ministry of Transportation Interchange file [and attached accident statistics], 1989-1993.
129. MTO. *Truck Collisions on Interchange Ramps*, 1974
130. CHIC. File Segment 5-17 - Approved Design Criteria Segment.
131. MTO. *The Social Cost of Motor Vehicle Accidents in Ontario*, 1994.

132. Ontario Provincial Police (OPP). Visual Media-Video tape-*OPP Concerns*, OPP, February 1997.
133. OPP. *An Analysis of Hwy. 403 Motor Vehicle Cross-over Collisions Occurring in the Port Credit Detachment Area, Jan. 1, 1993 to Aug. 31, 1996*, OPP, September 1996.
134. OPP. *Highway #407 Profile*, Rob Seaton, December 1996.
135. OTCC. *Highway 407 Central Project Annual Report*, Office of the Provincial Auditor.
136. Hamilton Associates. *Road Safety Audits: A Proactive Approach to Crash Prevention*, B. Locher, P.Eng., LL.B, Dr. F. Navin, P.Eng., S. Zein, P.Eng., 1977.
137. MTO. WC88-78-001 E30-1-MTO_Highway 407 Predesign Study, 8th Line (Brampton) to Emery Creek. Predesign synopsis Final Report (Giffels), August 1981.
138. MTO. WP88-78-002 E30-2-MTO_Highways 400-407 West of Weston Road Easterly to Jane Street and Finch Avenue Northerly to just North of Highway 7. Predesign synopsis, FENCO Consultants, June 1981.