SESSION B

Projects and Decision Making

Leere Seite
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Quality Assurance in the Eastern Scheldt Project

Assurance de la qualité dans le Projet de l'Escaut oriental

Qualitätssicherung beim Bau der Osterschelde-Sturmflutsperre

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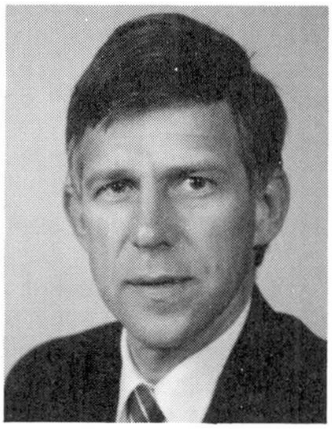


Wim Colenbrander, born 1942, received his civil engineering degree at the University of Technology Delft, The Netherlands. Since 1976 he has been involved in the Project Management Team of the Eastern Scheldt Storm Surge Barrier Construction.

SUMMARY

Quality Assurance in a multi-million project like the Eastern Scheldt Storm Surge Barrier is a necessity and covers the total building process: planning, design, construction and operation/maintenance. In the project no particular quality-assurance system has been introduced but the principles of the feedback loop have been followed. In general, quality-assurance has functioned satisfactory, especially the establishment of audit-days and Sections for Quality Control in the different areas of the project.

RÉSUMÉ

L'assurance de la qualité est indispensable dans un projet gigantesque, tel que celui de la protection côtière à l'embouchure de l'Escaut oriental. Elle concerne tout le processus de la construction: conception, projet, construction, exploitation et entretien. Aucun système réel d'assurance de la qualité n'a été introduit dans le projet mais les principes d'itérations successives ont été respectés. En général, le système appliqué a fonctionné de manière satisfaisante, en particulier par l'établissement de journées d'auditions et de sections de contrôle de qualité dans les différentes parties du projet.

ZUSAMMENFASSUNG

Bei so gewaltigen Projekten wie beispielsweise der Osterschelde-Sturmflutsperre ist Qualitätssicherung eine Notwendigkeit. Sie umfasst den ganzen Bauprozess von der Planung über Projektierung und Ausführung bis zu Nutzung und Instandhaltung. Im vorliegenden Fall wurde kein eigentliches Qualitätssicherungssystem eingeführt, jedoch war jeder Projektleiter in seinem Bereich für die Qualitätssicherung verantwortlich. Es zeigte sich, dass das Rückmeldeprinzip gut funktionierte. Vorteilhaft wirkten sich die Einführung von Audit-Tagen und von unabhängigen Sektionen für die Qualitätskontrolle in den verschiedenen Projektbereichen aus.

1. INTRODUCTION.

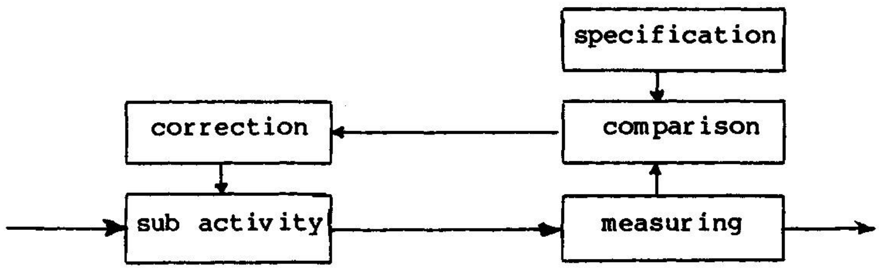
After the floods of 1953, which engulfed large areas of the Dutch delta, claiming 1835 lives, it was decided to the closure of the main tidal estuaries and inlets in the southwestern part of the Netherlands.
The various parts of this challenging project, called the Delta Project, were undertaken, one after the other, without delay.
The final part of the Delta Project was to be the closure of the Eastern Scheldt, which is the widest and deepest estuary in the area.
Due to environmental reasons, the Eastern Scheldt estuary was to be kept open in normal circumstances, but would be closed when storm surges were expected. The decision was made to build a storm surge barrier in the three tidal channels, the deepest parts of the estuary.
The Eastern Scheldt Barrier is estimated to come into use October, 4, 1986.

2. BRIEF DESCRIPTION OF THE BARRIER CONSTRUCTION.

The storm surge barrier, in all 3000 metres long, consists of 65 prefabricated concrete piers, weighing 18000 Tons, between which sliding steel gates have been installed. In normal conditions, the gates will be raised in order to maintain the tidal currents in the estuary, only when a storm is predicted the gates will be lowered. The foundation underneath the piers is formed by a prefabricated foundation mattress filled with sand and gravel as filtering agents. Between the piers prefabricated concrete sill-beams, weighing 2500 Tons, have been installed under water to reduce the flow-cross section and on top of the piers concrete bridge-box girders for traffic crossing.
Lastly there is a sill of rocky material of varying weight around and between the piers; the top layer is formed by basalt blocks weighing up to 10 Tons each.

3. CHOICE OF QUALITY-ASSURANCE SYSTEM

It is obvious that quality assurance in a "billions-project" like the Eastern Scheldt Storm Surge Barrier is of utmost importance.
The Project Management Team consisted of project-managers responsible for the main disciplines of the structure: foundation-, concrete-, steel works and research.
No uniform quality-assurance system has been introduced for the total project, but each project-manager was held responsible for the quality-assurance in his field.
In general, quality-assurance applications in the project were based on the principle of the "feed-back loop":



Measurable values are derived from functional requirements and design specifications, including target values and tolerances. Next the realised values in the construction procedure are to be compared with the target value and the tolerance. Subsequently a judgement of the quality of the product may be expressed. If the judgement is positive, the production can proceed. If the judgement is negative, the decision has to be made: acceptance, reparation or rejection of the product, as well as re-adjustments of the process or raw materials. The circle is to be closed by a report on the measuring results, the decisions and the re-adjustments.

4. QUALITY ASSURANCE APPLICATIONS THROUGHOUT THE PROJECT.

Quality Assurance comprises the total building process, including planning and design, as well as construction and maintenance.
In the following quality assurance applications will be discussed dealing with the total building process:

4.1. Planning.

The Minister of Public Works in the Netherlands is responsible for the choice of the plan to close the Eastern Scheldt by means of a storm surge barrier.
Check on the plan has been carried out by the Dutch Parliament after heated discussions. The Parliament agreed to the plan in 1976, under the condition that the project had to be subjected to a time- and cost target.
Next Rijkswaterstaat (Engineering Division of Public Works Department) was charged to make the detailed design, to tender the project and to supervise the execution.
Rijkswaterstaat reported to the Parliament every 3 months upon the progress of the project, related to technology, time-schedule and costs. In theory a good system, to inform the Parliament, but not a system to safequard time- and cost conditions at any moment. In general the information to the Parliament was dated about 4-6 months earlier, than the real situation.
When it became clear in a later stage that the time-target as well as the cost-target would be exceeded, the Parliamant established an independent commission of three experts to inquire the Parliament permanently during the remaining part of the execution.
Fortunately the commission concluded that the increase of costs and the delay in time-schedule could be justified. However, an earlier check on the progress of the project, would have opened the possibility for a review of the plan by the Parliament, at the moment that the conditions could not be fullfilled.

4.2. Design.

The design of the storm surge barrier comprises aspects as:
a. hydraulic boundery conditions;
b. foundation / sill part;
c. concrete part;
d. steel part.

Quality assurance related to the hydraulic conditions (waterlevel and waves) was hardly possible due to lack of data.
A certain quality-assurance has been found in a probabilistic approach of expecting waterlevels in relation to the wave-heights. In this approach a life-time of 200 years was estimated and a chance of failure 10^{-7}.
In addition, for all the important parts of the structure "error-trees" have been made in order to find the "weakest chain" in the design and/or execution.
The alternatives for the foundation of the piers have been made by the projectteam, and have been checked by external expertise in the soil-mechanics field (M.I.T: Prof. Lambe; University of Manchester: Prof. Rowe) by means of a constant auditing during the design period. Especially for the problem of liquefaction of the subsoil due to the cycling loading, a reliable solution have been found by the application of deep-compaction with vibrating needles.
Concerning the concrete part of the barrier, the ideal quality assurance would have been a complete "shadow-calculation" by an independent design-team. Unfortunately must be stated, that such a procedure is hardly impossible because of the organizational and especially financial problems. Therefore the choice has been made to check some critical parts of the design-calculations by external specialists (TNO-IBBC and University of Technology Delft). In this way external advice has been obtained concerning the shear force capacity, the "early" strenght of concrete and the durability aspects. This system of a selective check on critical parts has worked satisfactory and, in some cases, has resulted in a design-adaption.
The same procedure has been followed concerning the steel part of the barrier.
Critical parts of the gates, as well as the hydraulic equipment for moving the gates, has been checked by external consultancy.
The hydraulic system has been subjected to a probabilistic approach in order to determine the chance of failure of the system.
The study was carried out by an independent institute with experience in the field of nuclear power plants.

4.3. Construction phase.

4.3.1. Organization and personnel.

At the start of the concrete construction activities a temporary training-school has been founded on site. Skilled as wel as unskilled personnel were trained in the school in prefabricating the, in general, complicated formwork of the piers during about 8-12 weeks. By means of this special training, the quality of an important part of the concrete construction could be assured with implementation on quality, time-schedule and costs.
Another essential element for quality assurance was the establishment of independent sections for Quality Control. These sections worked independent of the production line and under direct responsibility of the Project Management Team.
These sections have been working in different fields of execution: foundation-, concrete- and steelworks. Due to the complexity of the design and the innovative developments in the execution, a high level of quality assurance was necessary, in which also design-expertise was represented.

In general terms, the task of the sections for quality-control was:
- to establish admissible values and tolerances;
- to design appopriate methods for approval;
- to saveguard the quality;
- to indicate solutions in case of disapproval;
- to propose process- improvements.

There was a regular consultation between the Project Management Team and the sections for Quality Control, especially in cases of important decisions.

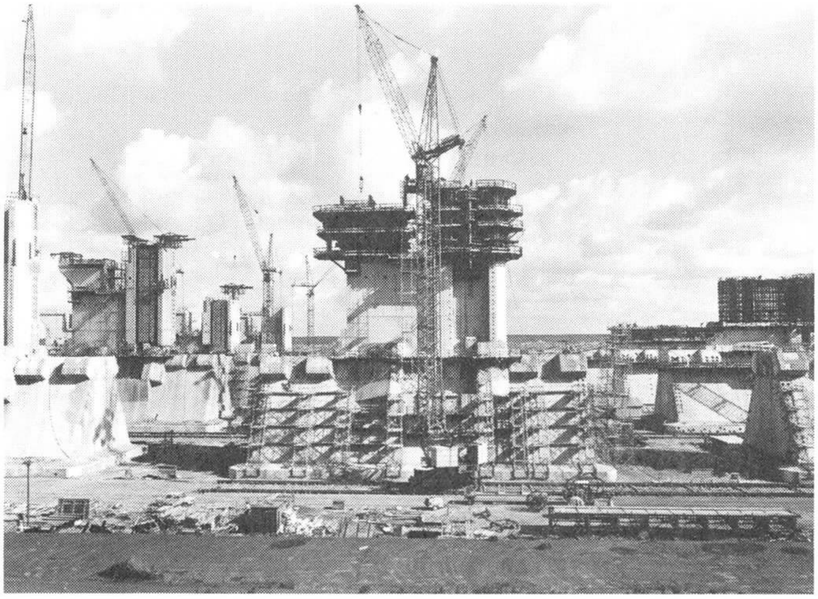


Photo 1 Piers under construction with formwork (Sept. '81)

4.3.2. Activities.

There are several examples of application of quality assurance in the construction phase, from which three examples will be given:

4.3.2.1. Negative overlap.

Since the centre to centre distance between the piers is 45 m and the width of the foundation mattress is 42 m, an opening remains of 3 m to cover the subsoil. This opening had to be filled bij ordinary gravel to be dumped in three layers (1/32 mm, 30/6/ mm and 40/230 mm) and this filter carried the name: negative overlap. It was essential for the stability of the barrier, that the "negative overlap" functioned perfectly.
The quality of the "negative overlap" is determined by the quality of the three layers individually. For that reason it was necessary to check the granual properties and the thickness of each layer, and to be sure that no sedimentation of sand had taken place on top of the layers.
The thickness of the layer can be measured by sounding, but the accuracy of sounding is dependent of the thickness of the dumped layer itself.
Therefore a process-control procedure has been established for the dumping of the layers 30/60 mm and 40/230 mm, with the following check-points:

- capacity belt conveyor;
- thickness layer on belt conveyer;
- level of material in dumping-pipe by remote-control system.
- waterpressure in dumping-pipe;
- current-velocity;
- movements of dumping-pontoon.

For every layer an additional check, after dumping, has been made by sounding and samples have been taken to check the granular composition. In this way the quality of the "negative overlap" has been assured by a double check.

4.3.2.2. Placing of the sill-beams.

Placing of the sill-beams was estimated as one of the most complicated and riskful operations.
On one side the working conditions between the piers (increasing current-velocity and irregular flow-pattern) had to be faced, because of the fact that the flow-crosssection was reduced with 30 %.
On the other hand the extreme small tolerances between piers and sill-beams (minimum 5 cm) and the necessary fixation of the beams.

Photo 2 Sill-beams in construction dock (Jan. '85)

For this complicated problem "audit-days" have been organized with a number of external specialists in offshore-techniques.
These audit-days resulted in remarkable tips for improvement in design and operation.
After some weeks this procedure has been repeated in order to come to an optimal and safe placing-operation.
These audit-days have proved that a procedure like that is a very appropriate one, or even stronger, in certain cases, is a necessity!

4.3.2.3. Hardening of concrete.

The independant section Quality Control for the concrete part has not only fulfilled the expectations, but has worked in an innovative way. To determine the step-by-step method of prestressing, it was a necessity to know the development of the compression strenght of the concrete in time.
Although the Dutch Code gives methods to investigate the hardening-strenght of concrete, the section Quality Control developed an innovative method adapted to the circumstances on site. In this method the hardening-cubes are kept in a waterbasin, of which the temperature, at any moment is the same as the temperature in the concrete pour on site.
The temperature-development in the concrete pour is measured contineously by thermo-couples and is directed to a computer-steered temperature regulator in the waterbasin. The temperature regulator (ΔT-regulator) takes care that the temperature development in the waterbassin with the hardening cubes is exactly the same as the temperature development in the pour on the site. In this way a very reliable interpretation of the hardening cubes was possible with a high level of accuracy.

4.4. Operation

For the operational use of the barrier, including maintenance aspects, it is very important to know the behaviour of the barrier under external loading and the critical parts to observe.
For every structural part of the barrier a "Certificate of Birth" has been made with all the necessary data, such as: dimensions, material properties, tolerances, shortcomings, etc.
E.g. Certificates of Birth has been made for the piers, the foundation mattresses and the soil mechanics properties of the subsoil.
In order to assure the quality of the barrier, also in the operational phase after completion, a "Maintenance Handbook" was established. In the handbook a description is given of the structural parts to consider and the frequency of inspection.
Also the way of inspection is indicated, in some cases a visual inspection is enough, in other cases measuring is necessary.
A significant example of measuring is the behaviour of the pore-pressures underneath the piers:
For the overall stability of the barrier the pore-pressure development in the foundation mattress and the subsoil is most critical.
Therefore two piers have been provided, in the construction phase, with a system of open ducts reaching from the top till the bottom of the piers.
In this way it is possible to install a measuring system in a later stage, to measure the pore-pressure development in the foundation mattress and the subsoil.
Installing of a measuring system in the foundation mattress means penetration of the mattress and chance of damage; experimental research, however, pointed out that a controlled penetration is possible and reliable.
The "Certificate of Birth" as well as the "Maintenance Handbook" will be handed over to the local authority in charge of the operation of the barrier.
In this way the quality of the barrier can be assured, also during the operational phase, after completion.

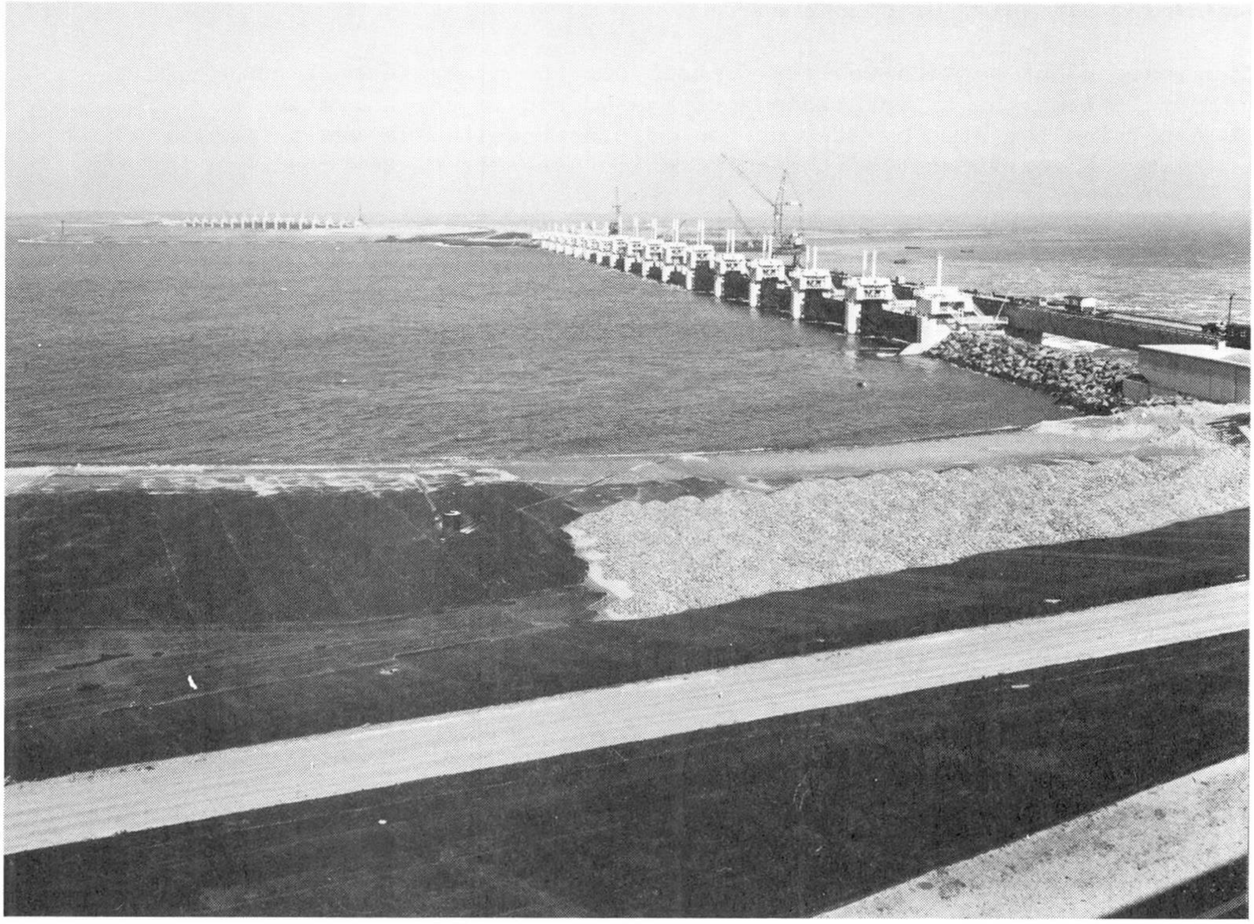


Photo 3 Completed part of storm surge barrier (April '86)

EPILOGUE

It may be stated that Quality Assurance has been applicated in the Eastern Scheldt Project. Also may be stated that at the start of the project no uniform quality-assurance system has been introduced.
During the progress of the project it became clear that quality-assurance was necessary in the different fields of the project. The consequence was that quality-assurance has been limited to the most important parts.
In 200 years, the estimated life-time of the barrier, the world may judge, if the Quality Assurance for the Eastern Scheldt Storm Surge Barrier was sufficient!

Safety Considerations for the Burlington Skyway Project

Aspects de sécurité dans le projet «Burlington Skyway»

Sicherheitsüberlegungen für die Burlington-Hochbrücke

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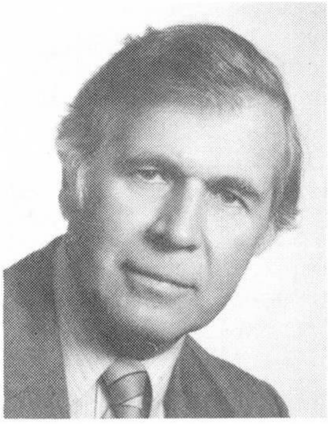

Roger Dorton received his Ph. D. from the University of Nottingham in 1954. He was a consulting engineer specializing in long span bridges before joining MTC in 1972. He is chairman of the Ontario Highway Bridge Design Code Committee, and a member of various AASHTO, TRB, ACI and CSCE Committees.

SUMMARY

The Burlington Skyway twinning is the first application of cast in place segmental concrete bridge construction in Ontario. The special safety and quality assurance features applied on the project are described including the tendering method, design considerations, site organization and construction procedures. The bridge has steel box girder approach spans and a concrete main span of 151 m. The project was completed ahead of schedule and within budget with no sacrifice of normal quality or safety.

RÉSUMÉ

Le pont de «Burlington Skyway» est la première application d'une construction de pont en encorbellement coulé sur place en Ontario. L'article explique les caractéristiques assurant la sécurité et la qualité de la construction, notamment les appels d'offres, les points importants du projet, l'organisation du chantier et les procédés de construction. Les sections des extrémités sont des poutres-caisson en acier; la poutre principale du milieu est en béton et a une portée de 151 m. Le projet a été terminé avant les délais fixés et dans les limites du budget alloué, sans compromettre ni la qualité ni la sécurité.

ZUSAMMENFASSUNG

Die Burlington-Zwillings-Hochbrücke ist die erste nach dem Taktschiebeverfahren gebaute Hohlkasten-Konstruktion in Ontario. Die speziellen Sicherheits- und Qualitätssicherungsmassnahmen werden beschrieben, wie auch das Ausschreibungsverfahren, besondere Entwurfsüberlegungen, die Baustellenorganisation und die Bauverfahren. Die Brückenauffahrten bestehen aus einer Stahl-Hohlkasten-Konstruktion, während die Hauptspannweite von 151 m mit Beton überbrückt wird. Das Projekt wurde ohne Einbussen an Sicherheit und Qualität vorzeitig und ohne Mehrkosten fertiggestellt.

1. INTRODUCTION

The Burlington Skyway project, Figure 1, consists of a new 4 lane high level bridge parallel to the original 4 lane bridge, opened in 1958. The skyway crosses the shipping canal entrance to Hamilton Harbour, in Ontario, Canada. The new bridge, which is the subject of this paper, was opened to traffic in 1985, and renamed the Burlington Bay James N. Allan Skyway. The original structure was then closed for rehabilitation, including deck replacement, and the completed 8 lane, twin structure, facility is scheduled for full operation in 1988.

The new structure is the largest bridge project undertaken by the owner, the Ontario Ministry of Transportation and Communications (MTC) since the construction of the original Burlington Skyway nearly 30 years ago. As it was tendered as one contract, unlike the original structure, it represents by far the largest single contract ever let by MTC, with a value of $38.80 million. The overall length of the new structure is 2215 m, consisting of 24 steel box girder approach spans each approximately 64 m in length, and a 3 span cast in place segmental concrete central unit with spans of 83 m, 151 m, 91 m..

Although cast in place segmental concrete spans of this size are not unusual, from the international perspective, this form of construction had not been used before in Ontario, and the technology was thus new to both the designers and local contractors. This situation, coupled with the fact that it was the longest span and largest project undertaken by MTC, necessitated that particular attention be paid to questions of safety and quality assurance. These special considerations of safety and quality assurance for all phases of the project, including tendering, design, site organization and construction are covered in the following sections.

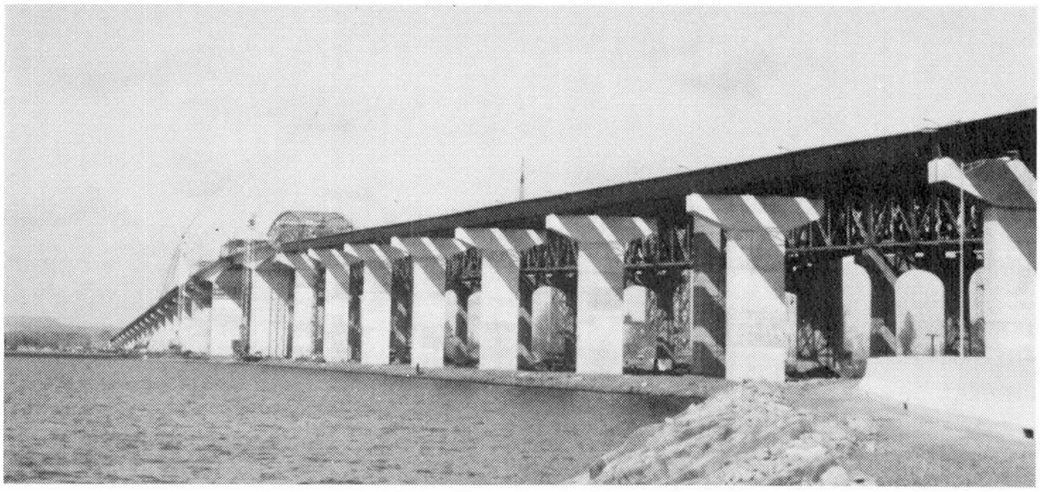

Fig. 1 Burlington Skyway under construction

2. BACKGROUND

In order that the Burlington Skyway project may be seen in the context of Ontario highway construction, the normal conditions and operations on MTC contracts will be briefly described.

The MTC has built and now has jurisdiction over nearly 3,000 highway bridges in the Province. They have generally been built by specialty highway contractors of medium size, and a $5 million contract would be considered large. These contractors usually have relatively small engineering back up, as they are rarely involved in design with the usual North American system of bidding on a single design package, fully detailed, with no alternative design opportunity. The contractors have extensive prestressed concrete experience, however, as cast in place post tensioned bridges have been the most common expressway interchange bridge type in Ontario for the last 20 years. There are well established pre-casting plants nearby, and a highly capable structural steel fabricating industry. General contractors manage contracts for a complete section of highway, including structures, and would normally sub-contract structural steel, reinforcing steel, prestressing and concrete supply for bridges.

The MTC Structural Office is responsible for the design of major structures, with 25% to 40% of the work in any year being carried out by consultants. The types of bridge structure normally used have become well established, with details standardized, so that contractors have become familiar with MTC projects. Similarly the specifications, quality assurance methods and contractural procedure are well established. MTC staff carry out on site inspection with a well trained body of inspectors and project supervisors, and the contractors submit shop drawings, falsework drawings and erection procedures for review before construction is authorized. This well established overall process minimizes surprises for the contractor, and has enabled a satisfactory level of quality and safety to be maintained, while encouraging competitive prices.

In moving away from the norm in both size and complexity for the Burlington Skyway project, it was decided that safety and quality would be best ensured by staying as close to the established MTC procedures as possible. Due to the unusual aspects of the project some additional procedures were required, as described, to make sure that the normal level of safety and quality was maintained or possibly improved.

3. TENDERING METHODS

Although the standard Canadian tendering method is to issue one design for contractors to bid, there is a growing tendency to issue alternative designs in different materials to increase competition and improve the chances of a lower bid. In Ontario the MTC practice is to have alternative designs prepared for bridges estimated to cost more than $3 million if preliminary designs do not indicate that one material has a clear advantage over another. The alternatives are fully detailed, and contractors are asked to bid on one or the other, with no provision for contractor redesigns. After a contract is signed the contractor may propose modifications, usually to the erection methods, provided the basic design is not altered. This is a limited application of the value engineering approach. This method does not compromise the usual level of safety or quality.

In North America some recent large projects have been called on the contractor design basis common in Europe. This approach has been slow to be adopted in North America as the contractors have not normally had the large design capability such as is present with major European contractors. Due to the size of the Burlington Skyway project, and the possible cost savings, this method of tendering was considered initially. It was rejected, however, as there was concern over a possible loss of design and contract administration control and hence a possible reduction in safety and quality. Another difficulty would be in establishing durability and serviceability criteria in a manner that would enable designs to be compared equitably. An additional factor was that the smaller Ontario contractors might be at a competitive disadvantage in a design-built tender compared to large American contractors. This was of particular concern as there was a construction recession in Canada at the time, and this large contract represented a significant portion of the MTC construction budget. The tendering method adopted was considered to give sufficient alternatives for competitive bidding, but at the same time maintain the usual level of control on design and contract administration. Complete designs and contract documents were prepared for a scheme with all steel superstructure, and another with all prestressed concrete superstructure. The main span lengths for both schemes were the same as they were controlled by site geometry requirements. The approach span lengths were varied, however, to suit the economic span for each material. These two designs enabled four bidding options to be offered, as follows:

A) All steel superstructure

B) All prestressed concrete superstructure

C) Steel approach spans and prestressed concrete main span

D) Prestressed concrete approach spans and steel main span.

In order to take advantage of these options it was necessary to tender the whole bridge as one contract, and each bidder could put in a tender price on only one of the options. As each of the options was equally acceptable to the owner, the award was based on low bid alone. No contractor design alternatives were permitted in accordance with normal MTC procedures.

In order to make sure the tendering process was fully understood, all contractors were obliged to attend a pre-bid meeting to pre-qualify as a bidder. They also had to name their major sub contractors in their bid, and name the prestressing specialist they would engage. This specialist had to be selected from a list approved by the MTC, of people with established experience in cast in place segmental construction. This requirement ensured that all contractor teams had the required expertise even if the general contractor had no direct experience of this form of construction.

A total of nine tenders were submitted, the lowest three all being for Option "C". Options "A" and "B" were also bid, but not "D". The contract was awarded to the low bidder, Pigott Investments Ltd., Hamilton, Ontario for a price of $38.8 million which was a few percent lower than the MTC in-house estimate. The winning option has a cast in place segmental concrete main span, Figure 2, and steel box girder approach spans with reinforced concrete deck, Figure 3.

Fig. 2 Main Span

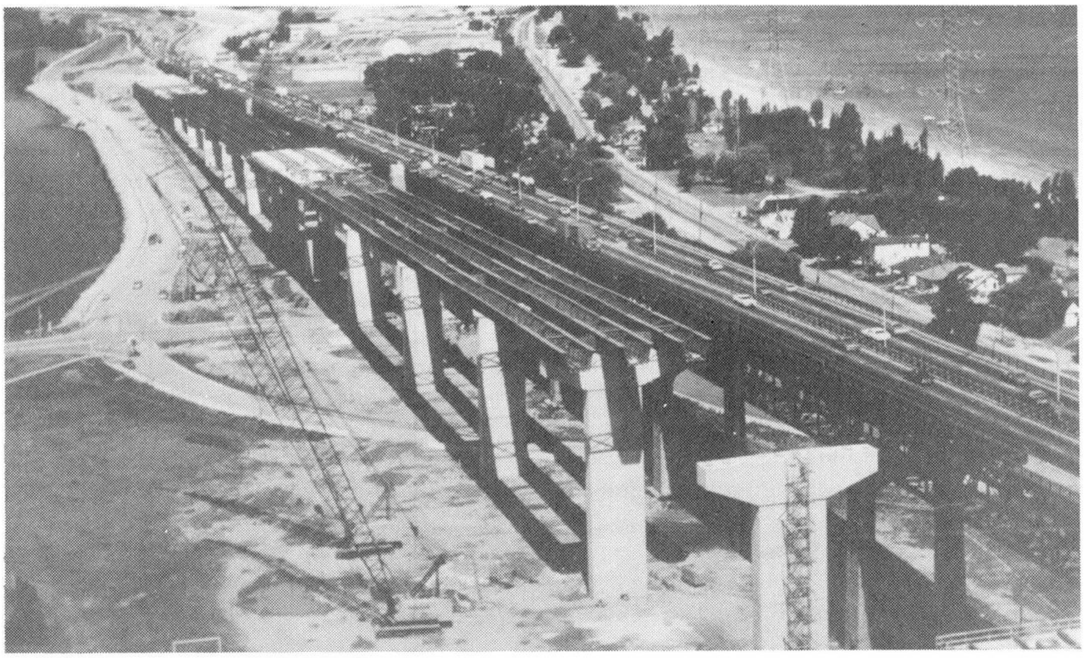

Fig. 3 Approach Spans

4. DESIGN CONSIDERATIONS

For the adopted tendering method, whereby full alternative designs were to be prepared, it was essential that the designs in both materials be competitive, economical, and as far as possible to be equally durable. It was decided that these criteria could best be met by preparing all designs in the MTC Structural Office. This office was large enough, with a staff of 80, to have expertise in all materials and design types, and had the equal confidence of the concrete and steel industries. The design code to be used was the newly developed Ontario Highway Bridge Design Code [1]. This was the largest project and longest span to which the code had been applied. The new code represented a major change from the working stress and load factor design approach of AASHTO [2] previously used in Ontario, to a fully limit states design approach calibrated to a prescribed safety level [3] . As several of the MTC Structural Office engineers had been active in the development and writing of the new code, this central office was the most logical location to carry out the design of this project.

The office had experience of precast segmental concrete construction, but not cast in place balanced cantilever construction. For this reason, DRC Consultants of New York were engaged to provide advice on this form of construction and the selection of the structural form. The DRC segmental construction computer program was used for the longitudinal design, and a MTC design engineer was assigned to New York during the running of the program. Direct input from the construction industry was obtained during the design phase. Existing liaison committees with the steel industry and prestressed concrete industry were used for advice on construction aspects during design development and in the selection of the most economical structural forms.

There were four basic designs developed for the bidding options: main span concrete, main span steel, approach spans concrete, and approach spans steel. Instead of having the design check carried out in-house, in the usual way, it was decided to use the expertise of local consultants and engage four different firms. Each firm carried out a completely independent check of one of the four basic designs. This approach was an extra safety precaution deemed advisable considering the size of the project and the fact that a relatively new design code was being applied. In addition, during the initial design, aspects of the

AASHTO Code were used as a check against the Ontario Code. This was done to identify, and subsequently obtain a satisfactory explanation of any significant variations between the two codes. This was thought to be advisable as the Ontario Code had not previously been applied to spans as long as the 151 m main span, and this span is at the limit of the prescribed applicability of this code.

The design was carried out with construction simplicity, and repetition of operations in mind, as an important way of reducing cost, but also the best way to obtain good construction quality and on-site safety. For the approaches, the span lengths are the same, 63.75 m, and only two pier sizes were used. The pier form selected was a very simple shaft with hammerhead cap, Figure 3, allowing maximum reuse of forms. The structural steel box girders were detailed to be shipped by road, and the maximum weight of 59 tonnes for any unit meant they could be readily handled by available equipment. For the segmental concrete main span the piers were designed to be integral with the superstructure, Figure 2, thus eliminating the need for any temporary supports during segment erection. The piers were designed to resist the unbalanced moment during segment construction, which was considered the safest approach, and enabled the design to be completed and detailed knowing the construction method. The twin cell box superstructure was kept simple with equal segment lengths, vertical webs, and straight rather than draped longitudinal strands.

The Ontario Code was calibrated to a target safety index of $\beta=3.5$ at the ultimate limit state. The question of safety during balanced cantilever erection of segmental concrete bridges has been addressed in the second edition, and the same safety level has been prescribed as for the completed bridge [4]. The consequences of failure during construction are normally considered less severe than for a bridge in service. However, for balanced cantilever construction loss of stability leads to total collapse and this was considered justification for calibrating to $\beta=3.5$. The construction condition is illustrated in Figure 4, along with possible applied loads. At the ultimate limit state the moment to be resisted by the pier is given by the following equation, which also shows the load factor applied to each load:

$$M_O = 1.05D_O + 1.10C_O + 1.25W_O + 1.05L_O + 1.10F_O + 1.10E_O - 1.00D_S - 0.90C_S - 0.75W_S - 0.90F_S$$

where subscripts "O" designate overturning moments and "S" stabilizing moments, and D = dead load, C = construction load, W = wind uplift, L = weight of last segment, F = weight of formwork, and E = edge load.

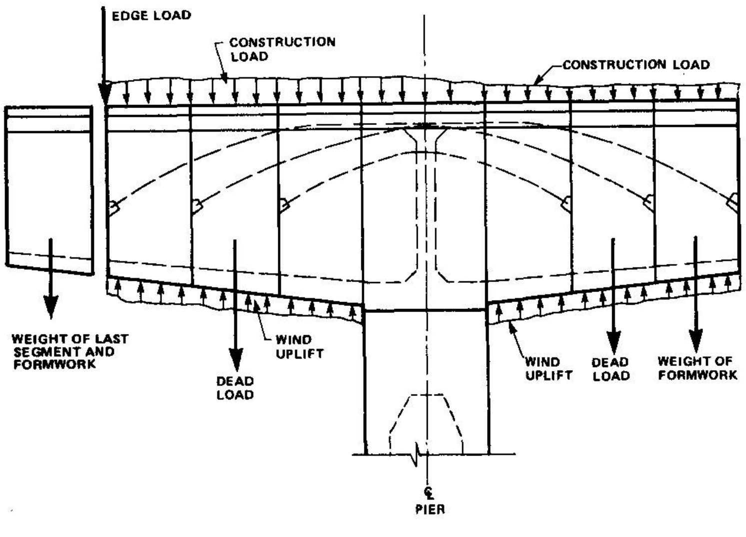

Fig. 4 Segmental Construction Loads

The Ontario Code also has been calibrated to prescribed safety levels at the various serviceability limit states, the values being less than $\beta = 3.5$. Although quality assurance is generally considered a function of construction control, long term quality can only be satisfied by considering suitably calibrated serviceability limit states and addressing durability aspects at the design stage. The Burlington Skyway is subject to winter salting of the roadway, and protection against this aggressive environment was of prime concern. The approach spans are in 6 span continuous units to minimize deck joints and their inherent leakage problem, deck drain pipes extend below the girder soffit, epoxy coated bars are used in the deck and piers, and extra thickness was used on the steel box girder webs adjacent to the original bridge to allow for brine splash. In addition, steel box girders were selected rather than plate girders, possibly at a cost premium, in order to minimize the steel surfaces exposed to the corrosive conditions.

More complete data on the design aspects of the project have been previously documented [5] .

5. SITE ORGANIZATION

The contractor, Pigott Investments Ltd., had no experience of segmental concrete construction, and had not been active in bridge building for many years. The contractor is one of the largest in Ontario, however, with considerable construction management capability developed on many large projects in the building and heavy construction fields. Pigott's site office was adjacent to the MTC site office, and the two offices collaborated closely on drawing approvals and held regular site meetings, so that all operations were planned and agreed in advance.

The specialist sub-contractor for cast in place segmental work was BBR Canada. The MTC site engineering staff, in addition to the Project Manager, was augmented by two engineers who had been involved with the design in the Structural Office. They carried out most of the shop drawing checking on site, so that differences could be discussed directly with little delay. All erection calculations, including cantilever deflections could similarly be agreed to on site, with the back up of head office staff when needed. In fact, there were few modifications required as the design contract documents gave full details such as reinforcing bar lists, prestressing details and segment deflections.

The contractor was very safety conscious, having safety movies shown, monthly safety meetings for all workers, and seminars given three times by the Construction Safety Association. This attention paid off with the accident frequency for the project being only 15% of the industry average, and there were no fatalities.

6. CONSTRUCTION PROCEDURES

The pier footing concrete was required to be placed in the dry, and due to the high water table in the filled land on which the piers were located, dewatering of the excavations was necessary. There was concern about settlement of the spread footings of the adjacent existing bridge as the water table was lowered, hence dewatering proceeded at a controlled rate as pier settlements and possible rotations were monitored. The maximum measured settlement of 17 mm was on the main span footing, and was considered an acceptable value. The only quality problem on the substructure occurred on the main span footing, where some thermal cracking took place near the surface. The size of the pour was such that concrete cooling provisions should have been included.

On the approach spans, a number of procedures were adopted that were not only cost effective but reduced the risk of accident. All the reinforcing steel for the hammerhead pier caps was prefabricated into cages on the ground, then lifted by crane into the forms, thus minimizing the work at high level. The steel box girders, supplied by Frankel Steel Ltd., were shipped to the site on the day of erection, pairs were bolted together and then erected. This operation minimized girder rehandling, as there was no site storage, and enabled half the field bolting to be done at ground level, in safety. For the reinforced concrete deck construction, stay-in-place metal forms inside the boxes gave an immediate and safe platform to work from. The wooden slab forms between boxes were large reusable custom built forms, which could be lowered from the deck slab level.

The main span segmental travelling forms were first assembled on the ground to fully check their operation before erection. A one-week turn around rate was achieved for the segment forms. The cantilever deflections were monitored on a weekly basis, at the same time of day to reduce thermal effects, and were always within 15 mm of the theoretical elevation. This was well within the allowable tolerance. The specified slump of 50 mm could have caused concrete placement and compaction problems, and the contractor opted to use a superplasticizer to increase the slump to 150 mm, with fully satisfactory results.

It was imperative that the segmental span be completed in one construction season, as a winter shut down would void the assumed schedule for cantilever construction and deflection control. This required completion close to the onset of winter, and thermocouples were installed to monitor temperatures after mid-October. When the temperature fell below 5°C warm air was introduced inside the boxes before cable grouting, and temperatures measured to ensure the thermal gradient in the girder did not exceed the design value. A contingency plan was established for possible winter concreting, but insulation and internal heaters were the only needs, as concreting and grouting were completed in November.

7. CONCLUDING REMARKS

The project was completed ahead of schedule, on budget, and with no extra claims. The contractor's safety record was excellent, and the quality of workmanship above average. The special safety and quality controls employed, as described, were a contributing factor to the overall success of the project, but of perhaps equal importance was the real concern by the contractor for the safety of his staff and the quality of the product.

All operations were well planned and detailed and there was good communication and co-operation on site between participants. This was helped by the clear delineation of responsibilities in the contract documents, and the following of normal MTC practices whenever possible. The resulting lack of serious problems, on the largest project ever undertaken by MTC, is perhaps best exemplified by the title of a paper given this year by the MTC Project Manager, "The Burlington Skyway, Another Routine Project".

8. ACKNOWLEDGEMENTS

The author wishes to acknowledge the assistance of A.C. Liu who was a member of the design team and later acted as a site engineer. Other members of the design team from MTC Structural Office included K.G. Bassi, W. Lin, G. Al-Bazi, M. Holowka, R. Haynes and C. Sadler, and the MTC Project Manager on site was J. Cullen.

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Economic and Socioecological Aspects of a European Motorway

Effets économiques et socio-écologiques d'une autoroute européenne

Ökonomische und sozio-oekologische Beurteilung einer europäischen Autobahn

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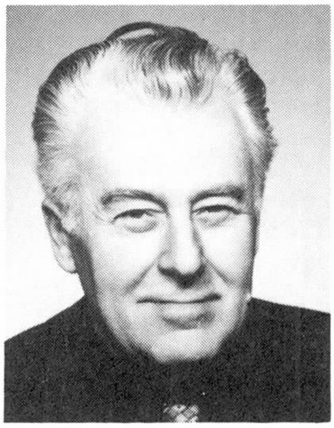


Lumír Borovička, born 1921, received his civil engineering and Ph. D. degree at the University of Prague, and has been responsible for bridge and road research, design and construction supervision in several design and research institutes in Czechoslovakia. He has acted as UNO expert in vocational training in civil engineering field in Asia and Africa.

SUMMARY

The governments of 10 European countries are preparing and gradually implementing a 10 000 km long motorway transport system connecting the Polish port Gdansk with the Turkish frontier to Iran. The Czechoslovakian experts have been entrusted with the preparation of «Guidelines for Economic, Aesthetic and Environmental Impact Assessment of the Trans-European North-South Motorway» and for the assessment of alternative projects. This new system enables the assessment of economic and environmental effects as well as the influence on the economic development of the regions through which the motorway passes.

RÉSUMÉ

Les gouvernements de dix pays européens préparent et réalisent un système autoroutier de 10 000 km reliant le port polonais de Gdansk avec la frontière turco-iranienne. L'élaboration d'un «Standard d'évaluations des effets économiques et socio-écologiques pour la comparaison des variantes des tronçons étudiés de l'autoroute européenne Nord-Sud» a été confiée aux experts tchécoslovaques. Le système nouveau permet d'évaluer globalement les différents aspects, les effets sur l'environnement et le développement des régions traversées par l'autoroute Nord-Sud.

ZUSAMMENFASSUNG

Im Auftrag von zehn europäischen Regierungen wird die 10 000 km lange transeuropäische Nord-Süd Autobahn projektiert und etappenweise ausgeführt. Nach ihrer Vollendung wird sie den polnischen Hafen Gdansk mit der Türkisch-Iranischen Grenze verbinden. Tschechoslowakische Experten wurden mit der Aufgabe betraut, Richtlinien für die Beurteilung von Alternativprojekten zu erarbeiten. Mit diesen lassen sich gleichzeitig ökonomische Aspekte und solche des Umweltschutzes sowie auch die Einflüsse auf die ökonomische Entwicklung der von der Autobahn tangierten Regionen beurteilen.

1. PRINCIPLES OF THE TEM-PROJECT

Since the mid of seventies ten European countries - Austria, Bulgaria, Czechoslovakia, Greece, Hungary, Italy, Poland, Romania, Turkey, Yugoslavia - have made significant efforts to coordinate the planning and successive realisation of the Trans-European North-South Motorway (TEM) connecting them (see Fig.1).

The project started within the framework of the United Nations Development Programme (UNDP) and the Economic Commission for Europe (ECE). Each country is responsible for the construction and financing of the sections of the motorway running through its own territory.

In order to achieve its objectives of the first phase (1978-83) the UNDP project undertook among others:
- the development and promotion of common standards of motorway design, maintenance and management (entrusted to Italian experts);
- an "origin and destination" survey and international traffic flow forecasting (entrusted to Danish experts);
- studies on environmental implications and socio-economic assessment of alternatives (entrusted to Czechoslovak experts);
- studies on synchronization of construction, investment and recommendations on construction technology.

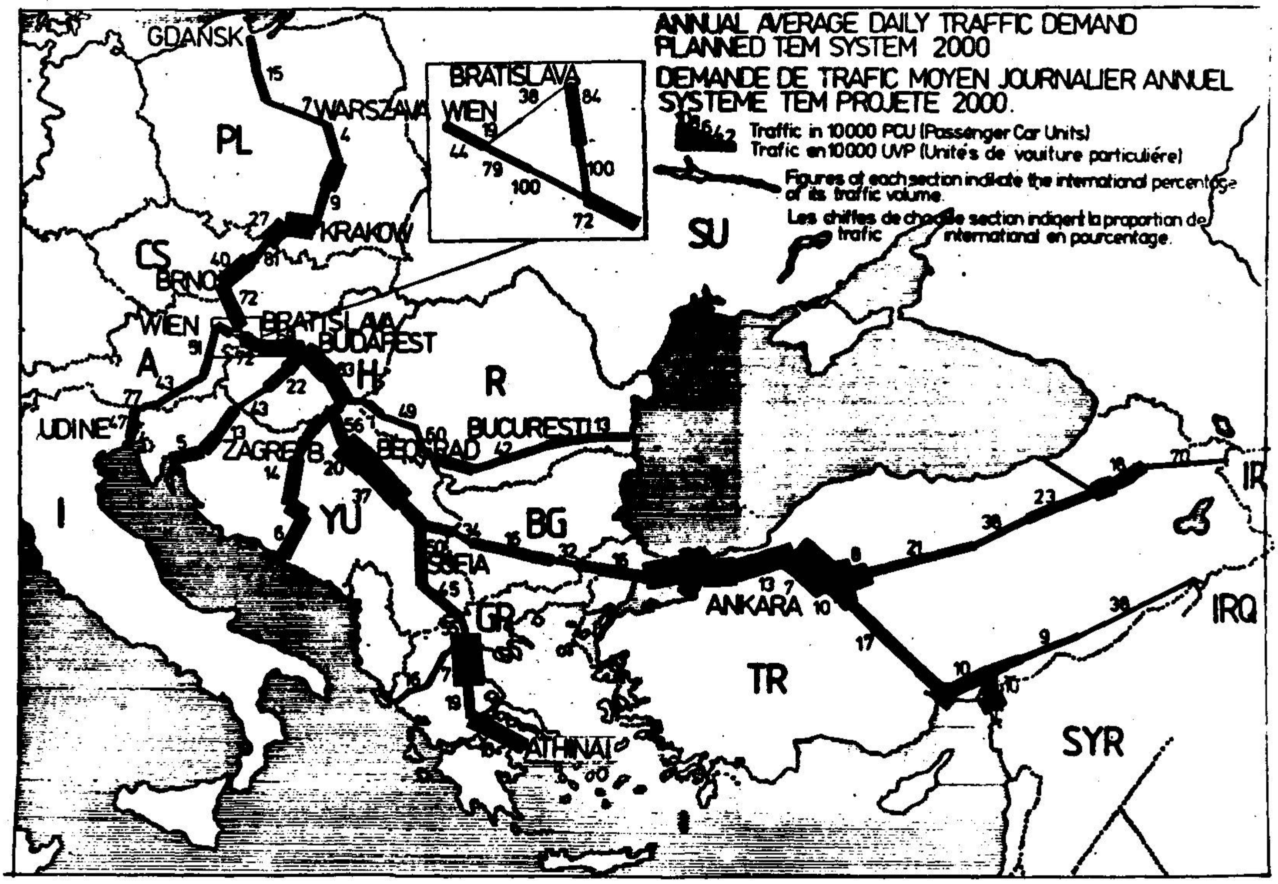


Fig.1 Average daily traffic forecast for the TEM system in 2000.

2. GUIDELINES FOR ECONOMIC, AESTHETIC AND ENVIRONMENTAL IMPACT ASSESSMENT FOR THE TRANS-EUROPEAN NORTH-SOUTH MOTORWAY

The elaboration of "Guidelines for impact assessment for the whole TEM project" - in following AECOTEM - has been entrusted to Czechoslovakia. This task has been completed and aided by useful international contacts - late 1983.

2.1 Principles of AECOTEM Guidelines

The planning and design of motorways represents a complex decision-making process. When determining the alignment of future motorways the designer is limited not only by the technical standards, regulations and by-laws but also by economic, aesthetic, ecological and other considerations prevailing in the particular region. As these aspects are very different in their nature - and the well-known existing methods of assessment of route variants based purely on monetary values cannot be satisfying enough to consider all aspects at once - a new method for complex assessment of variants is elaborated in the "AECOTEM Guidelines", which is based on value analysis of all different aspects to be taken into consideration.

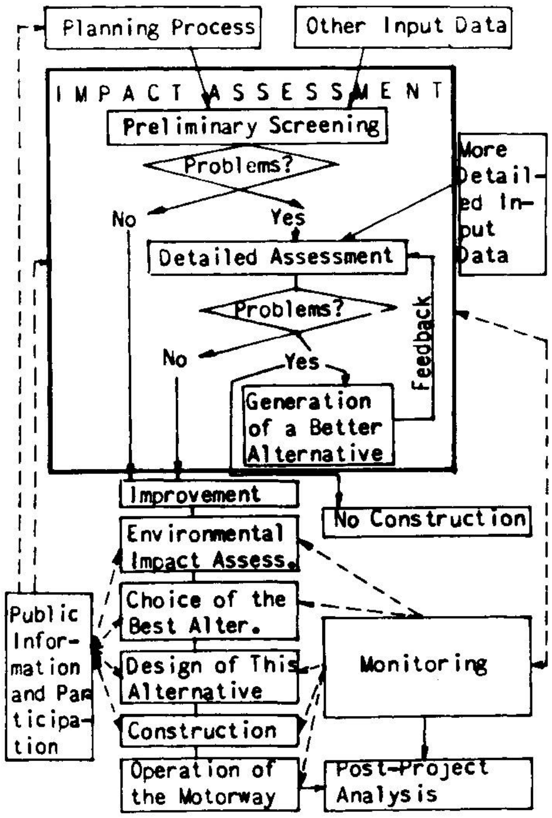


Fig.2 Impact assessment process

The AECOTEM Guidelines enable so - in a more advanced and secureful way than before -

- for the planners, civil engineers and consultants: to gain data - for each variant of rather costly motorway or its section - with increased security and quality and with possibility of differentiation of complexity of aspects; this enables them to recommend the truly most advantageous variant of the respective TEM section for implementation - advantageous for construction, exploitation, with minimum adverse effects for environment and most positive effects for the regional development;
- for the decision-makers: to possess means for appropriate decisions - with feed-back control - in selecting the best variant.

The assessment itself is usually carried out in two steps (preliminary screening and detailed assessment) and is often repeated (generation of new alternatives). It finishes with the final ranking of alternatives as a basis for the final decision which alternative to select for implementation. The scheme of usual approach recommended for TEM is indicated in Fig.2.

2.2 Preliminary Screening

When the first planning sketches, fesibility studies or preliminary alignment drawings - of a number of alternatives - are set up (available), it is necessary to analyze the advantages and disadvantages of different alternatives, taking into consideration (a) different activities emanating from TEM (construction, exploitation, regional development etc.), (b) different effects (e.g. investment costs, maintenance, traffic safety, users´ needs, environmental effects). The "Guidelines" recommend a special "Cause-Effect Matrix Method" -

MATRIX II VARIANT C			A. ACTIVITIES										
			A1					A2					A3
			Access roads	Earthworks	Drilling/blasting	Demolition	Pavements	Cuts and fills	Bridges, tunnels	Pavements	Traffic	Maintenance	Transport in region
E. AREAS OF POTENTIAL EFFECTS	Physical	Ground waters		-3	-2		-1	-2				-2	
		Surface waters						-2	-1	-1			
		Climate								+1	-1		
		Agricult. land								-2	-1		
		Forest land	-1							-1	-2		
		Erosion						-3					
		Noise	-1	-2	-1						-3		
	E	Fauna								-1	-1		
		Flora		-1								-1	
	AE	Blending/landsc.								-3			
		Architecture							-2	-1			
	Transport	Invest. costs					-2						
		Travel time									+2		+3
		Energy demands		-2							+1		+3
		Traffic safety	-1								+3		+1
		Maintenance											
	Social	Labour										+1	
		Housing				-2							+1
		Recreation	-1								-2		+3

Note: A1 - construction, A2 - operation, A3 - regional development, E - ecology, AE - aestretics

Fig.3 Example of Preliminary Screening

one matrix for each alternative - where their advantages and disadvantages are screened. The number of suitable alternatives for following design steps (e.g. preliminary designs) may be reasonably reduced to some two or three variants.

The system may be illustrated in Fig.3 on practical example of assessment of one of three alternatives of proposed motorway near Žilina, Czechoslovakia.

2.3 Detailed Assessment

It is carried out on the principle of value analysis of impacts of different types (not only monetary aspects) using the following four basic steps:

- selection of a system of indicators, by means of which the value of impacts in every alternative may be measured;
- evaluation of acceptability of each impact (partial evaluation);
- aggregation of partial evaluations into an overall assessment of every alternative (general evaluation);
- comparison of alternatives on the basis of their overall assessment (final ranking).

2.3.1 Description of impacts

The value of different impacts in all assessed alternatives should be compared (a) within the limits of one impact itself - considered for the assessment as "subgoal" as well as (b) within a group - considered as "goal" - of impacts of the similar character, (c) higher big group of grouped impacts - considered as "targets" - up to (d) total value of each alternative. The grouping of impacts "subgoals" (the number of which suggested in the Guidelines is 60) - into goals (10) and targets (3) is indicated in the "Decision Tree" - see Fig.4.

By this philosophy the Draft AECOTEM Guidelines significantly differ from and enlarge the well-known cost-benefit analysis systems previously used for the highway feasibility studies. This cost-benefit analysis was based on assessment of only those impacts which may be reasonably expressed on monetary terms.

Each impact considered for the assessment is "measured" by means of "indicator". This refers to a "subgoal I" or further detailed "subgoal II".

The proposed number of indicators (impacts) is not strictly binding and may be reasonably adapted to answer the needs. It is only stressed that the same selected system of indicators must be applied to all assessed alternatives of the same sector of the motorway.

2.3.2 Partial Evaluation

A uniform structure of indicator sheets is proposed. It always incorporates the following data (see examples of indicator sheets 4.1, 6.2):

Description - contains the definition of assessed impacts with technical unit by means of which the indicator value is expressed (min/trip, % of induced traffic, monetary value, number of exposed persons, cost/trip, points of satisfaction, etc.).

Presentation of results - summary of results, partial evaluation of the individual assessed alternatives (variants) in the target year.

Method of indicator value calculation - see indicators 4.1, 6.2.

Data sources - dtto

Calculation of indicator value - dtto.

Determination of value function - definition of value function which enables the transformation of "indicator value into the partial utility value (see vertical coordinates) of respective impact to express the degree of satisfaction (in points, within the limits from 0 - not advantageous - to 100 - the most advantageous alternative).

Possibility of application of cost-benefit analysis - see 4.1, 6.2.

Notes - dtto.

Examples of assessment of two typical subgoals I "cost of motorway construction" (indicator sheet 4.1) and "noise" (6.2) are given as follows on next page

2.3.3 General Evaluation of Every Alternative

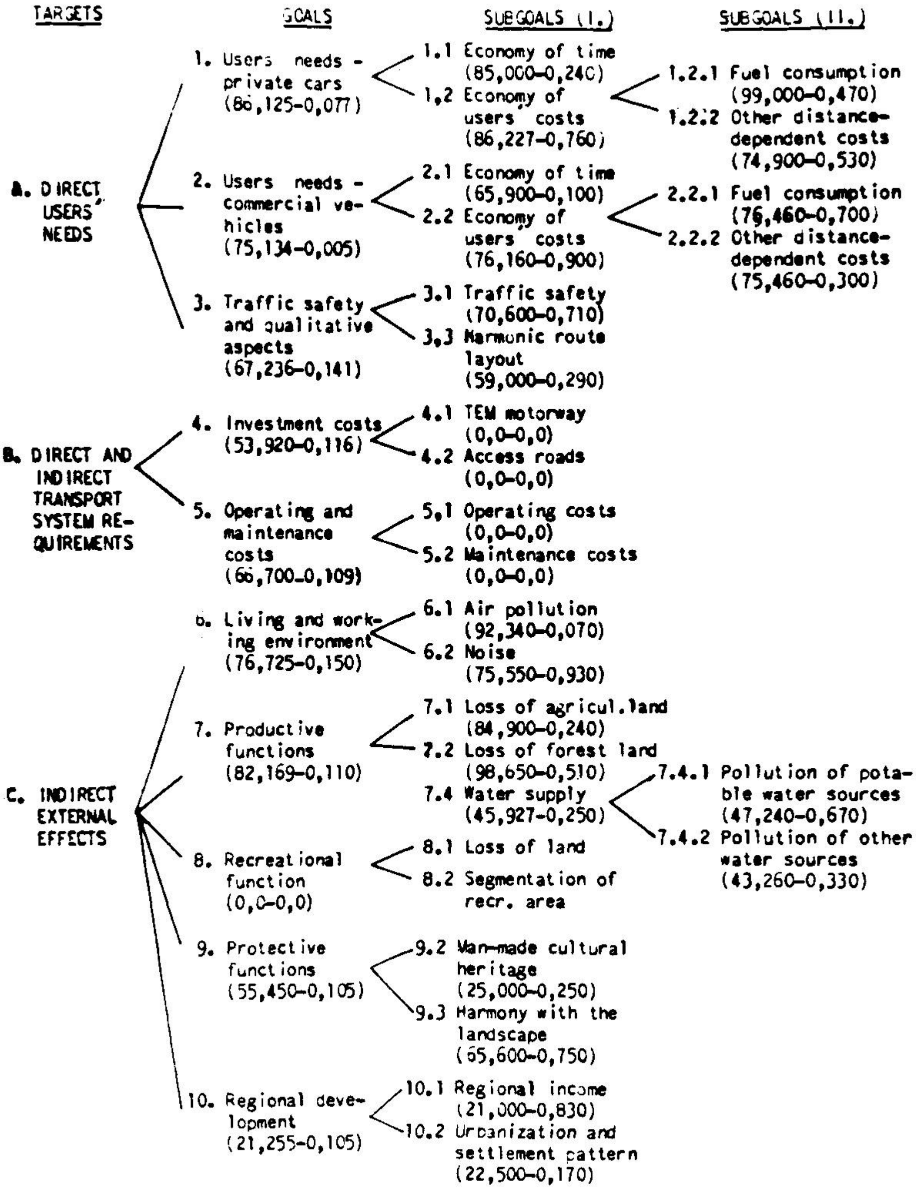


Fig.4 Decision Tree

Weighting of impacts

In the third step of assessment it is necessary to sum up the partial evaluations into an overall assessment of every alternative. Therefore partial utility values of individual impacts (subgoals) established in the preceding phases must be aggregated into relevant utility values of goals and further into total utility value of every alternative.

Since individual subgoals and goals are not of equal importance, their utility values cannot be aggregated directly (e.g. on the basis of arithmentic average). Their relative importance must be expressed by means of weighting. The weights determine the contribution of individual subgoals and goals to the overall value, i.e. the extent of their influence on the final result of assessment. The sum of weights considered in all relative groups (goals, subgoals) is always 1.000. The weighting is carried out as technical and preferential weighting.

Technical weighting concerns aggregation of impacts of an analogous type.

A. Indicator sheet for subgoal 4.1 (cost of construction)

Goal: Investment costs of infrastructure

Subgoal I: TEM motorway proper

Indicator: Investment costs of the TEM motorway

1. Description - overall investment costs of the planning and construction of the TEM section, incl. the costs of the right-of-way acquisition and design but without access roads of the motorway. The unit is represented in monetary value (Czechoslovak crowns- Kčs = 0,09 USD).

2. Presentation of results

Target year	Variant	Indicator value overall cost (mil.Kčs)	Partial utility value
1987	V_0	0	100
1987	V_1	4 833,1	48
1987	V_2	5 300,1	43

3. Method of indicator value calculation - individual alternatives are compared using the overall calculated investment costs obtained from on-going projects of the similar motorway sections.

4. Data sources - designs of alternatives and their calculated investment costs. "Average standard costs" per 1 km of motorway in different landscape types according to "Instruction of the Federal Ministry of Transport, CSSR".

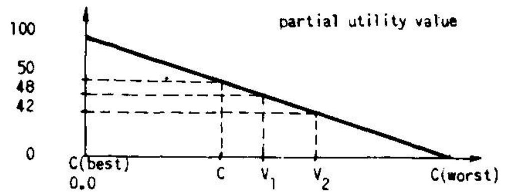
5. Calculation of indicator value - two alternatives of new TEM section V_1, V_2 are compared (with V_0 variant without motorway). Direct (bee-line) distance of their beginnings and ends is 73,5 km. The route of motorway sections-according to variants- is divided into smaller partial sections with regard to the landscape types through which the variants pass. The following table contains the necessary data.

Alternative	Partial section	Calculated costs (mil. Kčs)	Landscape type Type	Length of par. section (m)
V_1	a_1	1 732,4	B_2	28,4
	b_1	1 256,1	B_3	15,9
	c_1	1 844,6	B_1	40,1
	total	4 833,1		84,4
V_2	a_2	2 745,6	A_2	52,8
	b_2	2 554,5	B_2	39,3
	total	5 300,1		92,1

6. Determination of value function - partial utility value "50" of a value function is given to the "comparative standard cost value" (C) of a motorway connecting by bee-line D=73,5 km long the beginning and the end of all alternatives (increased by 15 % for the sinusoidal alignment) taking into consideration % share of landscape types, average standard investment costs per 1 km (see para 8).

$$C = 1,15 \cdot 73,5 \cdot \frac{58,2 \cdot 28,4 + 75,2 \cdot 15,9 + 45,5 \cdot 40,1}{84,4 + 92,1} + \frac{50,3 \cdot 52,8 + 58,2 \cdot 39,3}{84,4 + 92,1} = \underline{4\ 605,3 \text{ mil. Kčs}}$$

Partial utility value 100 corresponds to the state when no investment occurs, i.e. no TEM alternative is constructed and no existing network is reconstructed. Partial utility value for variants V_1, V_2 (with calculated costs 4 833 and 5 300 mil. Kčs) are taken from the diagram:



Costs of alternatives of TEM proper in mil Kčs

7. Possibility of application of cost-benefit analysis - the indicator is expressed directly in monetary terms.

8. Notes - Instructions of the Federal Ministry of Transport, CSSR, stipulates the following average standard costs per 1 km of motorway:

Landscape type	Standard costs in mil. Kčs per 1 km max.	average	min.
A_2	61,3	50,3	40,0
B_1	58,6	45,3	35,9
B_2	73,9	58,2	47,3
B_3	83,4	75,2	57,2

B. Indicator sheet for subgoal 6.2 (Impacts of traffic noise)

Goal: Living and working environment

Subgoal I: Noise

Indicator: Number of persons exposed to more than the maximum-permitted level of traffic noise

1. Description - the number of persons exposed to more than maximum-permitted level of traffic noise produced by traffic in the assessed TEM sector (in Czechoslovakia) and the part of the road network influenced by the motorway.

2. Presentation of results

Target year	Variant	Indicator value No. of persons	Partial utility value
2000	V_0	12 500	50
2000	V_1	4 500	82
2000	V_2	3 200	87,2

3. Method of indicator value calculation - the relevant area where the TEM passes is subdivided into minor zones related to their function to which maximum permissible value of traffic noise L_{Aeq} is attributed (in Czechoslovakia) - quiet zones (hospitals, schools etc.) 50 dB(A), housing zone 55dB(A), industrial zone 65dB(A). The total number of affected persons is calculated according to

$$N = N_1 + N_2 + \dots N_i \quad (1)$$

where N_1, N_2 ... N_i are numbers of persons in different zones.

4. Data sources - design (study) of the TEM sections, incl. population in the area in the zone of TEM influence, morphological characteristics of the ground

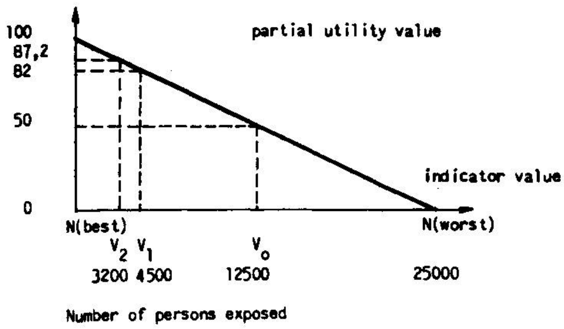
in the zone of TEM influence.

5. Calculation of indicator value - isophones L_{Aeq} (50,55,65 dB/A/) are drawn on the map along the TEM alignment and numbers of affected persons are calculated.

6. Determination of value function - if no person is affected by unacceptably high traffic noise level, the partial utility value equals to 100, the number of persons affected (in target year) with noise in the alternative without TEM gives p.u.v. 50.

7. Principle of monetarization - not required in the method of value analysis.

8. Notes



The weights are determined by calculation using quantificable relations between compared impacts. This weighting is usually used for the aggregation of elements on lower levels of the decision tree.

Preferential weightig concerns aggregation of principally different impacts (on higher levels of the decision tree). The weights are determined either directly, i.e. by inquiries among selected groups of people (representatives, population), or directly by analyses of preceding assessment, decisions or reactions and behaviour of certain groups of population.

Having accepted the values for weighting (w) the different impacts (subgoals I, II) in assessed TEM alteratives are aggregated successively on all levels of the decision tree (Fig.4). In this figure the "values" and "weights" for each assessed indicator and for the whole assessed variant are indicated in brackets (e.g. for goal 1: 86,125 - 0,077); for the whole variant the total value is 64,755. This example is taken from assessment of a section Kaplice-Freistadt (see later) and indicates the variant with the highest "total value".

2.3.4 Final Ranking of Alternatives

The total utility values of the individual alternatives obtained by the procedure described above serve as a basis for their mutual comparison and final decision or the generation of new alternatives. The higher this value the better the ranking of the particular alternative.

In the case when "final values" of alternatives do not differ too much, it is advisable to examine their stability by sensitivity tests. This may be done by reversing the ranking by changing values of individual impacts or changing value functions or changing weights or detailed disaggregation of goals with the highest influence and calculating the total utility value again.

3. TESTING THE NEW ASSESSMENT METHOD

The varification of utility of the "AECOTEM Guidelines" has been carried out - under the sponsorship of UNO and ECE - on selected test examples on (a) two sections (already in operation) of the Czechoslovak motorway system (Fig.3: sections near Žilina, 35-45 km long, mountaneous landscape; indicator sheets 4.1 and 6.2: section near Meziříčí, 73 km, hilly landscape) and (b) European E 14 route, section Kaplice (Czechoslovakia)-Freistadt (Austria), together with Austrian experts (Fig.4). The results were satisfactory and supported strongly the selection of the most advantageous alternative.

4. CONCLUSION AND ACKNOWLEDGEMENT

The value anylysis method for assessment of economic, aesthetic and sociological effects for the planning, construction and operation of all TEM sections -

as prepared in the "Guidelines" - is a new and complex way how to prepare or recommend selection of the best alternative to the decision-makers.

Elaboration of these "Guidelines" was entrusted to PRAGOPROJEKT, Consulting and Engineering Inc. for Highways and Bridges in Prague, Czechoslovakia (telex No. 123 560). Owing to a good team-work of all experts engaged (some 20 experts from Pragoprojekt, other professional institutes, ministries, Technical University - headed by Messrs. Nesvadba and Trčka) and thanks to a good collaboration with the board of representatives from governmental bodies of all TEM countries as well as from the U.N. Agencies (UNDP/UNEP/ECE) the "AECOTEM Guidelines" were elaborated (in 1983) and verified in "Applications" (1984). Both publications are considered the official U.N. materials.

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