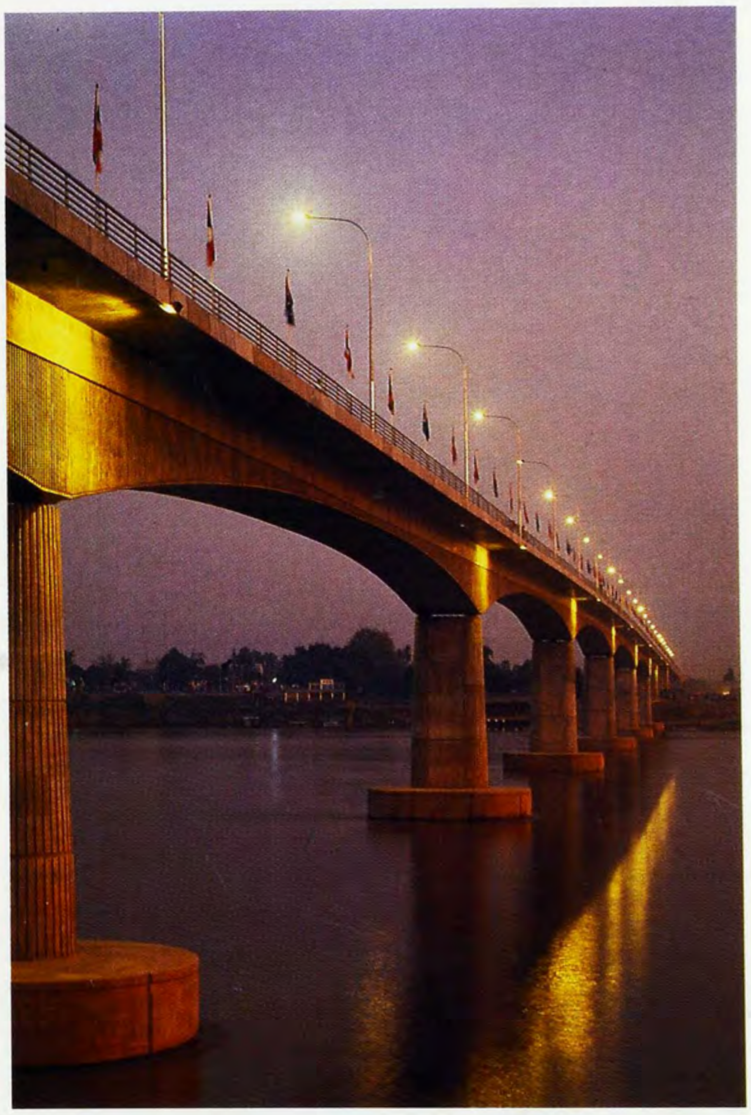
ROAD & TRANSPORT Research



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The photograph on the cover shows the Friendship Bridge over the Mekong River. Photograph courtesy of Maunsell Pty Ltd.

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ROAD & TRANSPORT Research

A journal of Australian and New Zealand research and practice

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Objectives

1 To provide a vehicle for the publication of analytical work in the road and related transport field, with a focus on work about Australasian conditions and of relevance to Australasian readers.

2 To encourage the reporting of original research, 'state-of-the-art' reviews and theoretical and applied analyses of topical issues and practices.

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This journal is published as part of a comprehensive technology transfer program. Other components include research reports, seminars and workshops and an information service providing access to national and international data bases.

Australian Road Research Board Ltd
500 Burwood Highway,
Vermont South,
Victoria, Australia
Postal Address
PO Box 156,
Nunawading, 3131,
Australia
Telephone (03) 881 1555
Fax (03) 887 8104
Email petermi@arrb.org.au

Australia builds the Friendship Bridge

P. Selby Smith

ABSTRACT

The Friendship Bridge, the first bridge to be built across the Mekong River south of China, creates the first fixed link between Thailand and Laos. The bridge was officially opened on 8 April by the Prime Ministers of Thailand, Laos and Australia, in the presence of the King of Thailand and the President of Laos. The design and construction of such a major project in this isolated part of the world was a significant achievement in technical and managerial terms as well as being an event of international political significance. This paper gives details of the significant aspects of the project which was fully funded by the Australian Aid Programme and planned, designed and built by Australians.

Editor's Note

Consulting companies play an essential yet largely unpublicised role in transport research in Australia and South East Asia.

At the invitation of the Editor, four companies accepted an invitation to report on recent projects. The papers included in this issue are excellent examples of the quality and range of work being undertaken.

It is hoped that a special consultants' issue will become an annual feature of Road and Transport Research.

The Friendship Bridge is the first international span across the Mekong River. It connects Thailand and Laos, and through Laos, creates a road corridor to both Vietnam and China (see *Fig. 1*). It is therefore a strategic link in an area of the world which has only recently stabilised after many years of political turmoil.

The Friendship Bridge has three main components: the bridge, approach roadworks and the riverbank protection. The bridge has an overall length of 1174 metres and consists of five main spans, each 105 metres long, across the river. The deck is 12.7 metres wide single-cell box girder. The deck depth varies over the structure, but has a maximum depth of 6.1 m over the main piers.

A joint venture between Maunsell and Sinclair Knight was responsible for the bridge's project management and design. The design work for the Friendship Bridge was prepared in Australia. The main bridge design was carried out in Maunsell's Melbourne office while the approach bridge, approach earthworks and the river bank protection works were designed in Sinclair Knight's Sydney office.

For Maunsell, the project is a benefit of a twenty-five year investment and development program in Asia. Having made the long march north into Asia in 1969, a survey undertaken last year by the New York based magazine *Engineering New Record* ranked the firm as sixth overall in Asia. The first five places were occupied by engineer-constructors.

With the completion of the Friendship Bridge, Maunsell–Sinclair Knight have continued to maintain a strong presence in the region. A team is working on the Asian Development Bank funded Seventh Road project in Laos, involving the rehabilitation of 210 kilometres of roads in southern Laos.

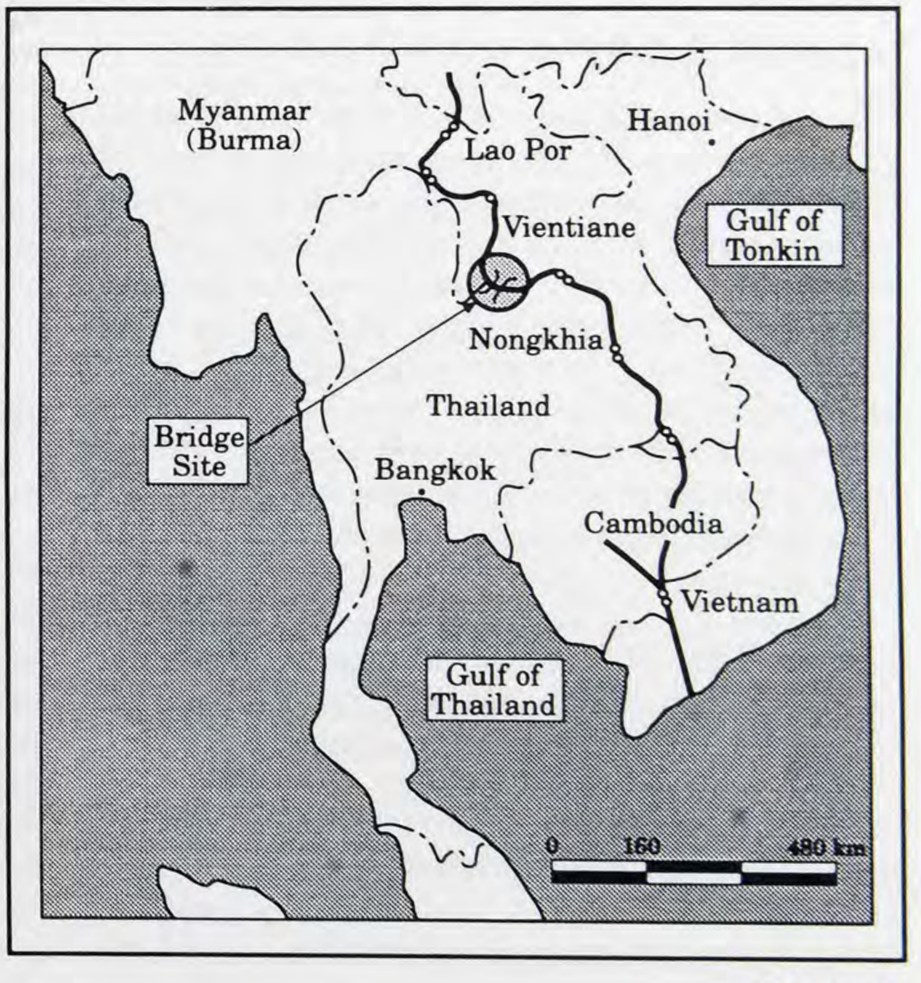


Figure 1

Map of the course of the Mekong River through South East Asia

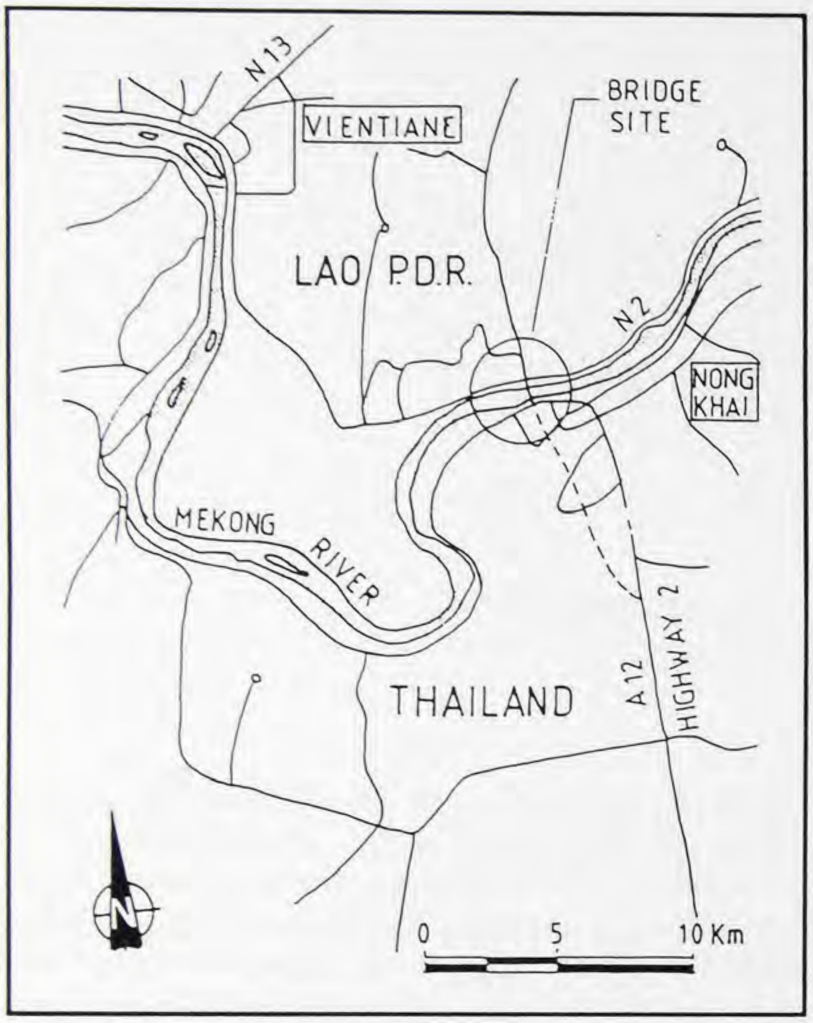


Figure 2

Locality map showing the location of the bridge

A LONG HISTORY

The Friendship Bridge is sited 1500 kilometres from the sea where the Mekong River is approximately 640 metres wide and has a bed level of between 152 and 155 metres above sea level (see *Fig. 2*). The river flow is highly seasonal and the river level varies during the year (on average) between 155 and 164 metres above sea level, while the velocity of flow varies between 1.5 and 2.5 metres per second. While the river is navigable by small ships for much of its length, waterfalls near the Lao/Cambodian border prevent navigation to the sea.

The 4200-km Mekong River rises in Tibet and flows through China, Burma, Laos, Thailand, Cambodia and Vietnam on its course to the sea. Before the Friendship Bridge's completion, the river's journey from China was marked by a lack of bridges and few ferry crossings.

The proposal to bridge the Mekong has a long history, with proposals being made in 1956 by the United States and in the early 1960s by the Royal Thai Railways who wished to extend their main north eastern line from Nong Khai across the river and across 20 kilometres of easy country to the Lao capital of Vientiane.

In 1965, the Lower Mekong Committee became involved with a proposal to bridge the Mekong and between 1967 and 1969, the Japanese consulting firm of Nippon Koei prepared a detailed proposal. The viability of their proposal was reviewed at length between 1969 and 1975, and options with and without a railway were considered. No definite decision had been taken to start work when the Communist government took control in Laos in December 1975 and the project lapsed.

The Australian proposal to provide a bridge began with an offer by the Prime Minister, Bob Hawke. In January 1989, he offered to provide a bridge as a gift to the two countries, and the offer was accepted. It was an opportune moment for such an offer to be made, given the realignment of the political situation in the region. Australia is well regarded by both countries and the involvement of a third country was seen as having the effect of keeping the project discussions focused on the project itself, rather than allowing other issues to intrude.

Following the acceptance of the offer, the Australian International Development and Assistance Bureau (AIDAB), a part of the Department of Foreign Affairs, undertook a Phase 1 study of the project to determine the nature of the proposed project in more detail, and selected consultants to assist them with the following stages of the project. A joint venture of Maunsell and Sinclair Knight was selected for this work, and work started in early 1990.

UPDATING THE FEASIBILITY STUDY

During 1990, the Maunsell–Sinclair Knight team prepared the feasibility study update report (FSU), which looked at the project's structural and engineering aspects as well as traffic use projections, economic value, environmental and social impacts, cost estimates and the future management of the bridge. The study was based on the work that had been previously undertaken as there was an expectation that the project would be similar, at least in concept, to that proposed by the Japanese some twenty five years earlier.

The engineering aspects of the FSU report involved a comprehensive series of studies which dealt with the following aspects of the proposed crossing:

(a) The feasibility and costs of providing for a future railway track along the centreline of the bridge.

(b) Navigational requirements for present and future river vessels.

(c) Site investigations to establish the nature of the ground conditions at the bridge site.

(d) Materials investigations to establish likely sources of materials for the project, particularly sand and aggregate for concrete and embankment fill materials.

(e) Approach roadworks and crossover configuration studies to optimise costs involved in switching traffic from the left side in Thailand to the right side in Laos.

(f) Environmental and social impact studies of the effect of the bridge on the local region and its communities.

(g) Hydrology and hydraulics studies to ascertain the impact of the bridge on the river regime and the need for river bank protection to ensure the long term integrity of the structure.

(h) Traffic, economic and financial studies to demonstrate the underlying viability of the Project.

(i) Alternative bridge arrangements to determine the most economic structural form consistent with the constraints imposed by the site and other design criteria. In all, a total of twelve different arrangements were investigated covering both steel and concrete construction in the span range of 35 m to 110 m.

Site conditions

The bridge is located on a straight stretch of the river just to the west of the northern Thai provincial capital of Nong Khai, and some two kilometres downstream of a major bend in the river. Historic maps of the area indicated that the river bed was relatively stable at the proposed site, with an average erosion rate of about 200 mm per year, but there was recent evidence of locally severe bank erosion approximately one kilometre downstream, where urgent river bank protection work was necessary.

Geotechnical investigations carried out during the study determined that the bed rock is essentially level and is situated a few metres below the river bed. It consists of a fine grained siltstone of moderate strength, has a low degree of jointing, and is consistent in its properties across the extent of the site.

The Lao bank of the river is relatively level at RL 168 while the Thai bank slopes towards the river and is some three metres lower. The soil above the rock differs on the two sides of the river. The Lao bank consists of relatively hard alluvial soils, while the Thai bank consists of slightly softer alluvial deposits and some loose bands of material at depth. These caused some concern during the design stage in regard to their ability to support high embankments. These differences are consistent with the erosion behaviour of the bridge at the site in that it is eroding the Lao bank and accreting on the Thai side.

Structural options

The results of the studies into the structural options for the bridge showed that the preferred structural solution would be as follows:

(a) A structure capable of supporting a future central railway track, with a central navigation clearance of 60 m x 10 m above a flood level of RL 167.

(b) A 650 m long main structure comprising a 12.7 m wide variable depth concrete box girder with spans up to 105 m.

(c) Approach structures of 240 m on the Thailand side and 260 m on the Laos side, each comprised of constant depth concrete box girders with spans up to 36 m.

(d) Approach embankments up to 10 m high extending from the bridge abutments to the Border Control Facilities on each side.

(e) A length of riverbank protection on the Lao side extending 350 m upstream and 100 m downstream of the bridge centreline.

The form of the bridge is governed by the limiting gradient of 1% for the railway track, and the requirements for a 10 m high by 60 m wide central navigation clearance, and a 5 m minimum vertical clearance over intersecting roads on either side of the river.

The draft final FSU report was completed in November 1990, and the three governments met in Canberra in December to discuss its findings. They agreed that the project should go ahead on the following basis:

(a) The bridge should be located close to the site selected by the Japanese study in 1967, just upstream of Nong Khai, and some 20 km to the south east of Vientiane.

(b) The bridge should cater for two lanes of highway traffic with provision for a future railway down the centreline of the bridge.

(c) The bridge should be built from prestressed concrete, and be a haunched box girder built by balanced cantilever methods from precast elements.

(d) The main bridge should have five main spans of 105 metres each and two end spans of 70 metres each.

(e) The bridge should extend past the roads which run parallel to the river on each bank and terminate on high embankments.

(f) The approach spans should be built as box girders from prestressed concrete.

(g) The riverbank on the Lao side should be provided with rock protection to prevent scour of the foundations.

(h) The traffic change over, where the traffic changed from driving on the left of the road (as in Thailand) to the right (as in Laos), should be located on the Lao bank of the river.

(i) The associated Border Control Facilities and connections to the national highway systems would be provided by the respective governments and the general arrangements of those facilities were agreed.

DESIGNING THE BRIDGE

Following the agreement between the three governments as to the form that the structure and the associated works should take, negotiations with the consultants in regard to the design phase of the work were commenced with the design starting in February 1991.

Design program

The design program was controlled by the need to have the contractor on site by the time that the river level fell in November 1991, so that the six month period of low water before June 1992 could be fully utilised for the construction of the foundations in the river. To achieve this, the following program was adopted:

1990	December	Call for registrations of interest from contractors
1991	January	Information meeting for interested contractors
	February	Receive submissions from interested contractors Commence further site investigations Commence final design
	March	Select tenderers Agree further design details with the three governments
	April	Provide tenderers with preliminary design details
	May	Complete tender documentation Call tenders
	June	Site meeting for tenderers
	July	Issue final design details
	August	Receive tenders Finalise independent proof check
	September	Select contractor, negotiate contract Agree with the Lao and Thai Governments
	October	Commence work on site

DESIGN CRITERIA

The bridge was designed to comply with the requirements of the NAASRA bridge design specification (1976). However the draft AUSTROADS bridge code was adopted for the design of all reinforced concrete elements.

Traffic live loading was taken as the envelope of either:

(a) normal T44 loading;

(b) abnormal vehicle loading (equivalent to a 320 tonne load platform); or

(c) railway loading designated UIC20.

River piers were designed to accommodate ship impact forces from errant vessels of up to 350 tonne displacement, travelling at speeds of up to 5 m per second, under flood conditions. This translated into a design impact force of 700 tonnes at a level some 10 m above the base of the columns.

The bridge site is located in a low seismic risk region and the bridge was able to be designed for a nominal unfactored quasi-static inertia force of just 6 per cent in both transverse and longitudinal directions.

The bridge was designed for a superimposed dead loading of 45 kN/m to allow for:

(a) a 75 mm thick asphaltic concrete wearing surface,

(b) concrete bridge parapets, steel balustrades and light masts of 14.6 kN/m each side,

(c) a central delineator and future rails and fixings of 1.9 kN/m, and

(d) an allowance for future services of 3 kN/m.

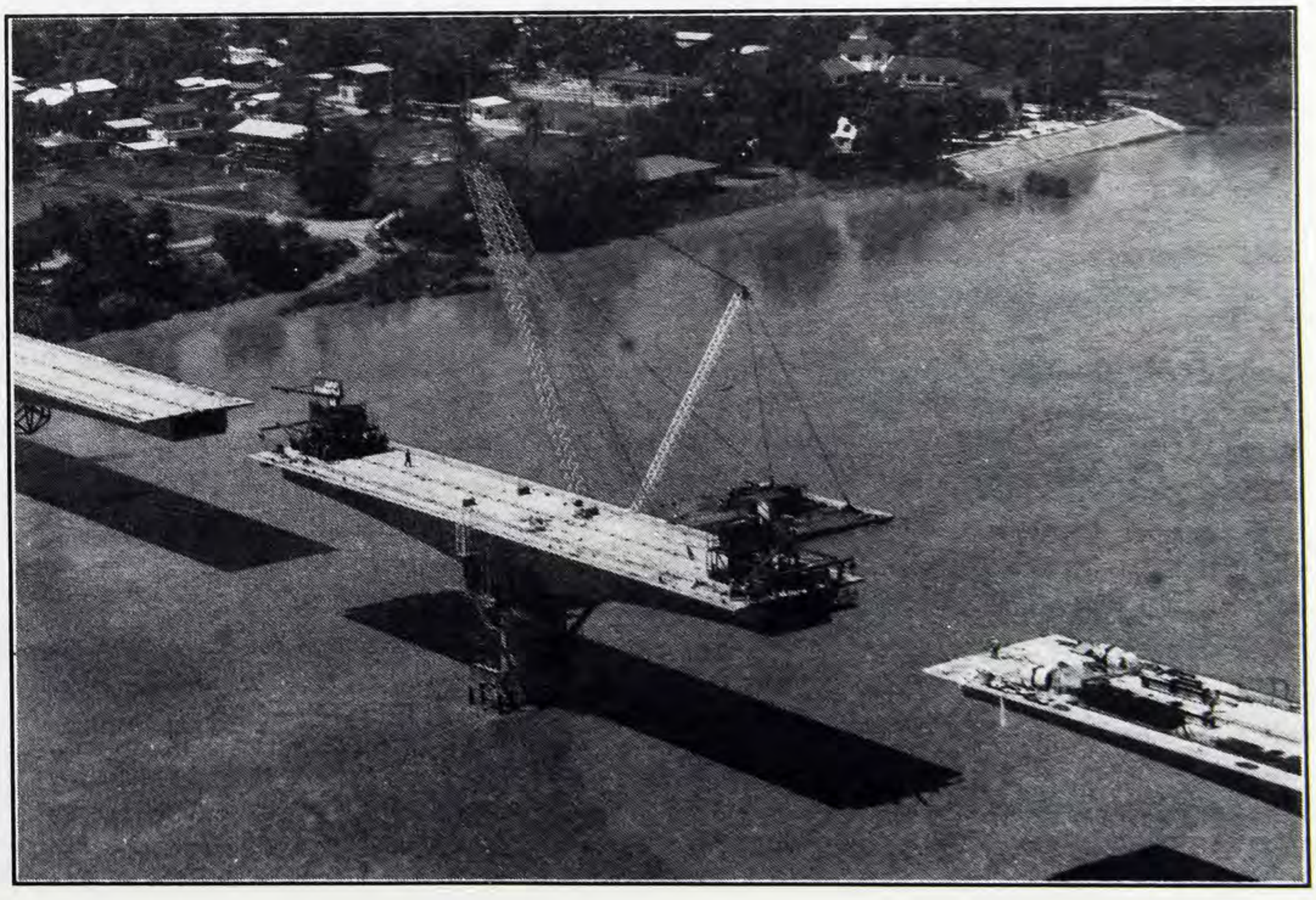
Materials

After much effort to ensure that high quality concrete could be produced in the area, and extensive testing of the available limestone aggregates, it was decided that it would be appropriate to specify Grade 45 concrete for the bridge superstructure and the driven precast piles, and Grade 32 concrete for the other concrete to be used on the project.

Sand dredged from the bed of the river and aggregate from local Thai quarries would be used and the cement would be sourced from Thailand. The reinforcing and prestressing steel for the project would be sourced from Australia.

Articulation of the bridge

In the longitudinal direction, the bridge is articulated in three separate sections corresponding to the main structure and the two approach



The bridge under construction

structures. The main structure is fixed near the centre of the river at Pier 11 under normal service conditions and at both Piers 11 and 12 under dynamic loading conditions, such as seismic or train braking effects.

The approach structures are each fixed at the abutments and the main expansion joints between the separate structures are located at the transition piers on each bank.

The main structure

The main structure has an overall length of 665 m, consisting of five 105 m internal spans and two 70 m end spans. The deck is a 12.7 m wide single cell box girder with a variable depth ranging from 6.1 m at the piers to 2.6 m at the midspan of internal spans and 2.1 m at the transition with the approach structures. The longitudinal prestressing is designed on the basis of balanced cantilever construction using match cast epoxy jointed segments weighing up to 73 tonnes (pier diaphragm segments). The bridge's longitudinal section is shown in *Fig. 3*.

Each balanced cantilever consists of 45 segments with adjacent cantilevers joined together by a 1.2 m long *in situ* concrete section. End spans require a further seven segments to reach the transition piers.

Individual segments are designed to be temporarily supported by a total of five longitudinal prestressing bars, and the stability of the cantilevers is achieved by the provision of pier head brackets, and additional props in the case of end spans.

Both the transverse and longitudinal design of the bridge superstructure were governed by the train loading, and the box girder section was detailed as a reinforced concrete element for this loading.

Longitudinal prestressing of the girder consists of a combination of 19/12.7 mm strand tendons and 36 mm diameter prestressing bars located and anchored as follows:

(a) top flange tendons for balanced cantilever — anchored at face of precast segments (52 maximum),

(b) top flange tendons for midspan negative moment capacity — anchored at top flange/web blisters (4 maximum),

(c) top flange bars for erection of last seven end span segments — anchored at the face of segment (28 maximum),

(d) bottom flange tendons for midspan positive moment capacity — anchored at bottom flange blisters (25 maximum), and

(e) segment attachment bars — anchored at the face of the segments (three top flange and two bottom flange).

The prestressing design was carried out by means of the program CREAP (Concrete Rheological Effects Analysis Program) based on the requirement for a minimum residual compressive stress across the glued joints of 1.5 MPa under Group 1 loading.

The main bridge superstructure is supported on solid reinforced concrete piers some 15 m above pile cap level. The columns are rectangular in shape with semi-circular ends and are tapered in both directions with minimum cross section of 5.7 m by 2.6 m. The piers are supported on 1,500 mm diameter steel cased cast-in-place piles socketed into the underlying siltstone.

The approach structures

The approach structures at the Thai and Lao ends of the main bridge have overall lengths of 269 m and 240 m respectively with maximum spans of 36 m.

The deck is a 12.7 m wide single cell box girder with a constant depth of 2.1 m for compatibility with the end spans of the main bridge.

For tender purposes the approach bridge superstructure was designed to be constructed *in situ* span by span on falsework commencing from the abutments on each side of the river.

Longitudinal prestressing consisted of a maximum of 4 No 42/12.7 mm stressing tendons per web with coupling points located at the quarter span positions.

As detailed below, the preferred tenderer proposed to streamline the erection process by adopting a match cast segmental construction method for the approach structures, similar to that being used for the main bridge. This led to a redesign of the longitudinal prestressing for the approaches to

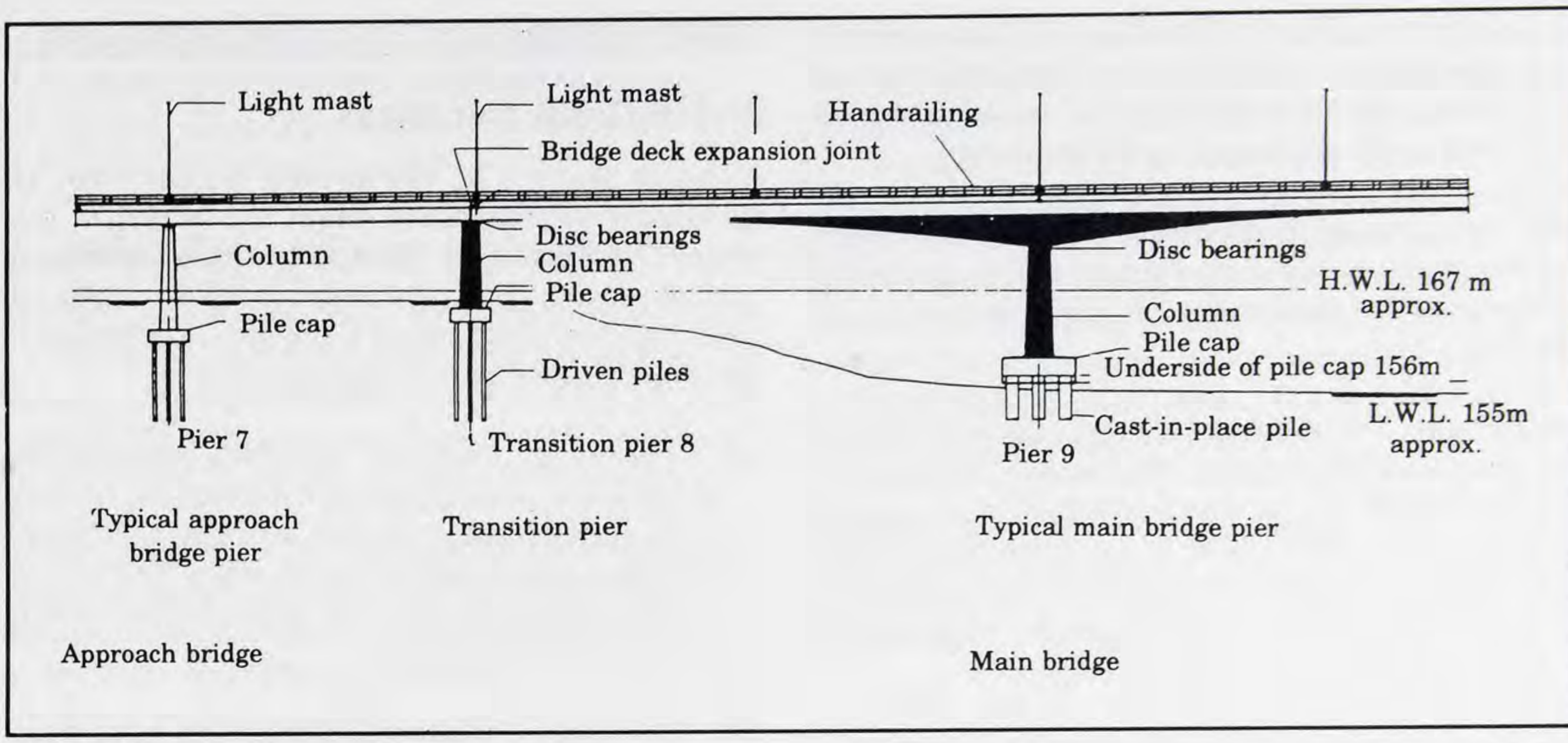


Figure 2

The longitudinal section of the bridge superstructure

suit the erection of 3.42 m long segments in balanced cantilever.

Longitudinal prestressing of the girder consists of a combination of 19/12.7 mm strand tendons and 36 mm diameter prestressing bars located and anchored as follows:

(a) top flange tendons for balanced cantilever — anchored at face of precast segments (18 maximum),

(b) top flange continuity tendons — anchored at top flange/web blisters (2 maximum), and

(c) bottom flange tendons for midspan positive moment capacity — anchored at bottom flange blisters (10 maximum).

Each balanced cantilever consists of 11 segments with adjacent cantilevers joined together with 225 mm wide *in situ* joint.

As for the main bridge the balanced cantilevers are stabilised during erection with props off the pier pile caps. Out-of-balance end span segments are supported on falsework to avoid the need for additional top flange prestressing as required for the main bridge.

The approach bridge superstructure is supported on solid reinforced concrete piers with columns of a similar shape to the main bridge columns but of a reduced thickness and without the architectural fluting. Piers are founded on 450 mm octagonal prestressed concrete driven piles.

FOUNDATIONS

Main bridge foundations

The main bridge foundations within the river channel were designed to be supported on socketed 1.5 m diameter piles to take advantage of the close proximity of the underlying siltstone. Each pier foundation consists of eight piles (ten in the case of the fixed Piers 11 and 12) with overall pile cap dimensions of 14.0 and 9.0 m.

Piles are designed to be 'fixed' at both rock and pile cap level and analysed using the program PIGLET on the basis on the basis of the following parameters:

(a) scour depth of 5 m,

(b) average rock modulus of 1000 MPa,

(c) Poisson's ratio of 0.25,

(d) pile concrete strength 32 MPa,

(e) pile failure to govern lateral loading, and

(f) vertical pile capacity assessed in accordance with the Williams, Johnston and Donald method given in 'The Design of Socketed

Piles in Weak Rock' — International Conference on Structural Foundations on Rock, Sydney 1980 (based on a minimum factor of safety against failure of 3).

The resulting analysis indicated the requirement for a minimum pile socket length of 6 m, governed principally by the limiting criteria under lateral loading.

Under the two critical loading combinations of longitudinal seismic and ship impact effects peak, ultimate pile loads reach 20,000 kN in axial compression, 8000 kN in axial tension and 1400 kN in shear. These pile loads correspond to a seismic inertia force of 0.08 g and a ship impact force of 1000 tonnes at RL 167 m.

It was envisaged that the piles would be constructed by conventional tremie concrete methods inside driven steel casings. The piles were detailed with considerable confinement reinforcement at the potential plastic hinge locations, and *in situ* tremie concrete trials and lateral loading tests were specified to ensure that the design intent was realised.

Because of the considerable fluctuations in the river level, the pile caps were designed to be constructed in two stages involving an external shell structure cast in the dry on extensions to the steel casings, followed by an *in situ* infill pour with the shell sealed off in its final position.

Approach bridge foundations

The approach bridge foundations, including the transition Piers 8 and 15 and the abutments, are founded on driven 450 mm octagonal prestressed concrete piles with a maximum working axial compression capacity of 1300 kN and maximum working tension capacity of 350 kN.

All piles are vertical and founded in dense sands and gravels overlying the siltstone. The maximum anticipated pile length was of the order of 23 m.

Abutment piles on the Thai side were partly slip coated with bitumen to minimise down drag forces resulting from the construction of the 10 m high approach embankment. Lateral loading on the abutments is carried by deadman anchors located at ground level some 14.0 m behind the abutment walls.

OTHER FEATURES OF THE BRIDGE'S DESIGN

Architectural treatment

A major feature of the bridge design was its architectural treatment. From the outset of the project, it was decided to give the structure a special appearance consistent with its regional importance and its role as a showpiece of present-day Australian engineering expertise.

(a) To present a smooth interface between the approach and main structure, vertical ribbing was introduced on the main bridge segments. This appears below the smooth line of the approach structure and accents a haunched zone over the piers.

(b) The semicircular ends of the river piers were vertically ribbed to extend the theme of the haunched zone over the piers.

(c) The abutments were given a more imposing appearance symbolic of an international gateway.

Putting the last segment in place

(d) The abutment concrete has an exposed river aggregate finish and is capped with precinct polished limestone units supporting two flag poles at each abutment.

Providing for a railway in the future

The bridge is designed with provision for a single 1.0 m gauge railway track along its centreline. This requirement was met by providing 360 mm wide by 100 mm deep blockouts in the box girder deck sufficient to accommodate 134 mm deep rail sections. The blockouts will be filled with bituminous concrete until such time as the rail is required. Expansion joints are deviated below the blockouts and installed with removable components to facilitate the future installation of the rails. At the main expansion joints at Piers 8 and 15 the rails themselves span over the joints and have their own expansion joints located within 550 mm wide x 130 mm deep x 10,000 mm long blockouts in the approach girder deck slab.

The track alignment deviates from the bridge centreline just beyond the abutments and will ultimately link up with approach embankments to the south of the bridge. In combined train/road usage, traffic lights will be required to control the passage of road vehicles when trains are approaching the bridge.

Bearings and expansion joints

The bridge is supported at each pier on two disc bearings ranging in vertical working load capacity from 7000 kN to 20,000 kN.

The abutment bearings are each required to accommodate longitudinal unfactored forces of 3000 kN and the fixed bearings at Pier 11 some 4000 kN. Lateral forces are designed to be accommodated by a single bearing at each support; however, both bearings are provided with lateral load capacity. In the longitudinal direction all bearings are similarly provided with shear plates clear of the normal thermal range to guard against the possibility of separation in the event of unexpected seismic events.

Pier 12 is provided with a separate seismic restraint consisting of 6 No. 75 tonne 'Colebrand' shock transmission units as a means of sharing any dynamic loadings in the longitudinal direction. The device is located centrally between the bridge bearings.

The bridge is provided with two types of expansion joint. At Piers 8 and 15 where a total movement range of 470 mm is anticipated, the joint will be a 7 element modular extension joint, whereas at the abutments with nominal movements only, a single element joint is all that is required. Both joint types had to be modified to accommodate the future rail track by ensuring that their main members pass under the space that will be required to allow the track to span the joint and continue to the rail expansion joint location.

Bridge furniture and services

The bridge deck was provided with the following furnishings:

(a) New Jersey profile *in situ* crash barriers (between roadway and footpath),

(b) precast edge panels,

(c) steel edge balustrades,

(d) precast walkway slabs,

(e) precast centreline delineators,

(f) drainage scuppers at 12 m intervals, and

(g) an asphaltic concrete wearing course (50 mm thick).

The services include:

(a) overhead roadway lighting (located on the upstream side at 35 m intervals),

(b) emergency telephones with handsets at 300 m centres,

(c) pier lighting both upstream and downstream of all river and transition piers,

(d) internal box girder lights and power at 35 m intervals,

(e) navigation lights centrally and either side in the central channel, and

(f) provision for two future 150 mm diameter water or fuel mains.

Bridge services are located in trenches along the northern shoulder of the approach roadway and within the service voids beneath the footpaths on the bridge. The abutments have an accessible 2.0 m x 2.5 m service chamber for the installation of future services to the bridge.

THE APPROACH ROADWAYS

On the Thai side

The Thai approach roadway consists of an approximately 640 metre long two-lane road on fill, with the embankment height varying from 10 metres at the abutment to 4 metres at the limit of contract.

The formation width is 16 metres, and consists of two 3.5 metre travelling lanes, two 2.5 shoulders, two 1.5 metre grassed verges and a 1 metre median zone with a 0.5 m concrete median.

On each side of the embankment there is a maintenance access road which extends from the limit of contract and joins under the abutment. This road is 3.5 metres wide and will give access to the landscaped areas, the lower parts of the batters and the drains, so that grass cutting, drain cleaning and other maintenance activities can be carried out. Pedestrians will be able to use this road for access to the Border Control Facility from the batter sidewalk.

The Thai Department of Highways (DOH) standard for minimum road pavement levels liable to be affected by flooding requires that the top of the formation be a minimum of 0.3 metres above a 1 in 25 year average recurrence interval flood. Allowing for crossfall and pavement thickness, the design road centreline should not be lower than one metre above the 25 year HWL.

Hydraulic analysis of Mekong River flood levels indicated that a 1 in 25 year flood would have a reduced level (RL) of about 167.5 and so the minimum centreline level for the embankment was set at RL 168.5.

This resulted in embankments 10 metres high on relatively compressible clay subsoils. Extensive soil testing and analysis was carried out which showed that settlement of up to 500 mm could be expected. Various measures including horizontal filters using siltstone fill and pre-loading were considered in order to reduce settlement.

Lao approach roadway

The Lao approach roadway consists of an approximately 160 metre long two-lane road which separates into two one-lane ramps leading to the traffic changeover. The traffic changeover is necessary as vehicles in Thailand travel on the left side of the road while vehicles in Laos drive on the right. The embankment height varies from eight metres at the Laos abutment to one metre at the limit of contract at the start of the Border Control Facilities (BCF).

The formation width and cross-sectional geometry of the two-lane section of road is the same as on the Thai side. Each ramp has a formation width of 10 metres, comprising a single 3.5 metre lane with shoulders 2.5 and 1.0 metre wide as well as 1.5 metre wide verges. This configuration will provide sufficient room to allow for passing stationary vehicles in case of accidents or breakdowns. Near the crossover the ramps are widened to a formation width of 12 m, comprising two lanes 3.5 m wide, two shoulders 1 m wide and 1.5 m verges. This provides storage for vehicles near the border control facilities.

Slope protection

As it will be difficult for plants to grow on the embankment batter directly under the bridge abutment because there will be insufficient sunlight, grouted stone pitching has been provided.

In the vicinity of the abutments, the outer batter slope of the maintenance access road is also to be covered with stone pitching, with Reno mattresses extending from the batter toe. This is to afford extra protection against possible scouring at the abutments during major floods.

Concrete pavement

In accordance with the design brief, concrete pavement was adopted for the bridge approach.

The concrete pavement thickness was designed in accordance with the Design Traffic Loading Procedure R2 of NAASRA's Pavement Design Specification, 1987 using the criteria specified in Appendix H.

The adopted pavement features:

(a) 32 MPa unreinforced concrete, 200 mm thick;

(b) 5 MPa cement bound base, 125 mm thick.

Flexible pavement

Because of the relatively large embankment settlements anticipated adjacent to the abutments in the area of the future railway tracks and in order to more easily accommodate the future alteration of profile required to suit the curve of the railway, a flexible pavement was considered more appropriate. Alternative flexible pavements considered included:

(a) granular pavement with thick AC surfacing

(b) semi rigid pavement (bound sub-base with thick AC surfacing), and

(c) full depth AC.

Option (a) was selected as the preferred alternative based on settlement and maintenance.

The pavement will consist of three layers of asphaltic concrete and two layers of aggregate.

Gravel pavement

The maintenance access roads are gravel-surfaced, in keeping with their low vehicular traffic levels and their use as pedestrian pathways. These roads will be used and maintained by the contractor during construction as haul roads for embankment fill. On completion of construction works they will be covered with 100 mm of gravel.

RIVER BANK PROTECTION

The river

At the bridge site the river is flowing through deposits of alluvium along a highland plain. The riverbanks are generally composite in nature, consisting of layers of non-cohesive and cohesive materials. The course of the river is characterised by a series of relatively gentle meanders, with radius of curvature to width ratios ranging from 5 to 10. Overall, the average water surface gradient along this part of the river is 8-10 cm/km.

Review and analysis of data

Excellent data were available from a number of sources and a frequency analysis of the flood levels was carried out from the 53 years of records. The results indicated that the flood level for the 1 in 100 year flood event was RL 167.95 m in the vicinity of the bridge, which corresponded to a discharge of 22,500 m^3/s.

These analyses formed the basis of the design level for the top of the riverbank works, as well as the minimum bridge elevation.

The effectiveness of any riverbank works was first assessed from a geomorphological perspective. The possibility of a major shift in the river course, lateral bend migration rates, and the extent of river bed scour anticipated during the life of the structure, were some of the factors investigated. The local processes of bank erosion were then identified prior to the formulation of an appropriate method of bank protection.

Major shift in river course

Several historical channels are evident on the inside of two bends within 10 km upstream of the bridge site. It was possible that these channels would act as floodways during heavy flooding, which raised the concern that a new shortened channel could form within the lifespan to the bridge and threaten to outflank the bridge.

An investigation of the topographical and geological features in the area was carried out in order to assess the possibility of this change occurring. However, it was found that the many natural highlands, man-made levees and road embankments existing in the area precluded many short-cuts for the river. The relatively small overbank floodways and flow velocities (upper limit of 3 m/s in a major flood) were also considered to be inadequate to pose such a threat.

Lateral bend erosion

It is apparent that the river upstream of the site has shifted laterally by erosion of the concave (outer) bank and deposition of the convex (inner) bend. These historical rates of erosion were quantified using aerial photographs and maps. The maps provided a history of bank erosion at the bridge site over the last 21 years.

The maximum erosion was found to occur on the apex of the bend about 1.5 km upstream of the bridge site. The extent of bank retreat was found to be about 60 metres over this period, which equated to an erosion rate of about 3 m/year. At the bridge site at the downstream end of the bend the rate of erosion was found to average one metre per year. These rates were generally substantiated by the landowners fronting the river.

Based on these estimates a movement of 100 metres could be expected at the bridge site over the next

100 years. Erosion at the outer bend upstream was also expected to increase as the bend radius decreased, with the bend expected to tend to translate downstream. Overall, the results indicated that a translation of 300 metres at the site over the next 100 years was not unrealistic.

Riverbank protection works were therefore considered essential in controlling the rate of bank retreat. While it would have been desirable to protect the entire bend, in order to minimise the risks of erosion at the bridge site, it was not considered to be economically viable as it involved protecting over 6 km of the riverbank. The gradual, rather than catastrophic, nature of the erosion was also such that it would provide ample time for any remedial work to be carried out should there be a threat to the bridge.

Based on these considerations and in order to protect several water supply pipelines in the area, it was concluded that the protection of the riverbank to a distance 300 metres upstream and 100 metres downstream of the bridge centreline was adequate.

Processes of riverbank erosion

The cross-sectional profiles of the riverbank at the bridge site were found to be similar and generally steep and almost vertical, particularly at the upper 2-3 metres. The banks were in general 6-7 metres high and consisted of clay to a depth of 6 m, silts for the next 1.5 m and sands down to a depth of 1.8 m

Bank failure mechanisms were identified to be a combination of the following:

(a) Saturation of the riverbank during flooding and rapid drawdown of the river level relative to the groundwater table, leading to slumping of the banks. This rapid drawdown was a characteristic of the Mekong. A maximum difference of 3 m between the river and groundwater table water levels was found to be fairly representative.

(b) Vertical tension cracks at the upper zone, which weaken the stability of the bank. A maximum tension crack depth of up to 3 m was found to be not uncommon, particularly during the dry season.

(c) Transient or permanent bed scour at the bank toe which led to undermining, steepening and increase in riverbank height, thus initiating progressive collapse of the upper bank. This was a primary process of bank retreat considered to be critical to the effectiveness of the riverbank works.

(d) Seepage through lenses of sand and coarser material sandwiched between layers of cohesive banks, leading to piping failures.

(e) Wave action from wind and boats.

These factors were incorporated in the detailed analyses and design of the riverbank protection works.

Design of the riverbank protection

The detailed design of the riverbank protection work was based on the factors discussed in the preceding sections.

Bank stability under various loading conditions, including the effects of rapid drawdown of the river level, tension cracks, construction loads, and seismic loads was analysed using the computer programs XSLOPE and STABL5P. Overall, the riverbank was designed to have a minimum factor of safety of 1.3 under static loads and 1.1 under earthquake conditions.

Protection of the bank toe against basal scour was considered to be of fundamental importance to the stability of the protection works. It was essential that the protective apron had the ability to readjust its geometry to fill and pave any scoured profile, thus preventing further scour, without affecting the overall stability of the riverbank works. The two major types of protection considered to have the flexibility to accommodate these changes were (1) rip-rap protection and (2) a wired rock basket (reno mattress) system. Both options were considered in detail, including aspects of reliability, durability and cost.

A reno mattress system was finally selected on the basis of a number of factors. They were: past success in use in the Mekong River; durability at least equal to that for rip-rap, if not better; lower maintenance costs; and initial capital costs of only half that for a rip-rap system.

Other factors in favour of reno mattress construction were that the rock volume and rock sizes required were much smaller, which meant that the rocks were more readily available. While $4000 m^3$ of rock was required for the reno mattresses 16,000 m^3 of rock, or four times the volume, was required for the rip rap system. Similarly, the size of rock required for the reno mattresses was only to up to 120 mm, in comparison to a size of up to 500 mm for rip rap.

The riverbank was designed at side slopes of 1:2 down to a berm level of RL 160 m. The top of the protection works was set at RL 168 m. The berm, which is 3.5 m wide, was provided to facilitate ease of construction and maintenance. The apron length below the berm was also sized to ensure that the reno mattress would rotate and protect any scour profile down to a minimum river bed scour level of RL 149.5.

OTHER FEATURES OF THE PROJECT

The Mekong River Bridge Project is not only a major technical task in a remote part of the world, but also the fact that it straddles a sensitive international frontier and is a gift from a third country have given the project some interesting contractual and managerial aspects.

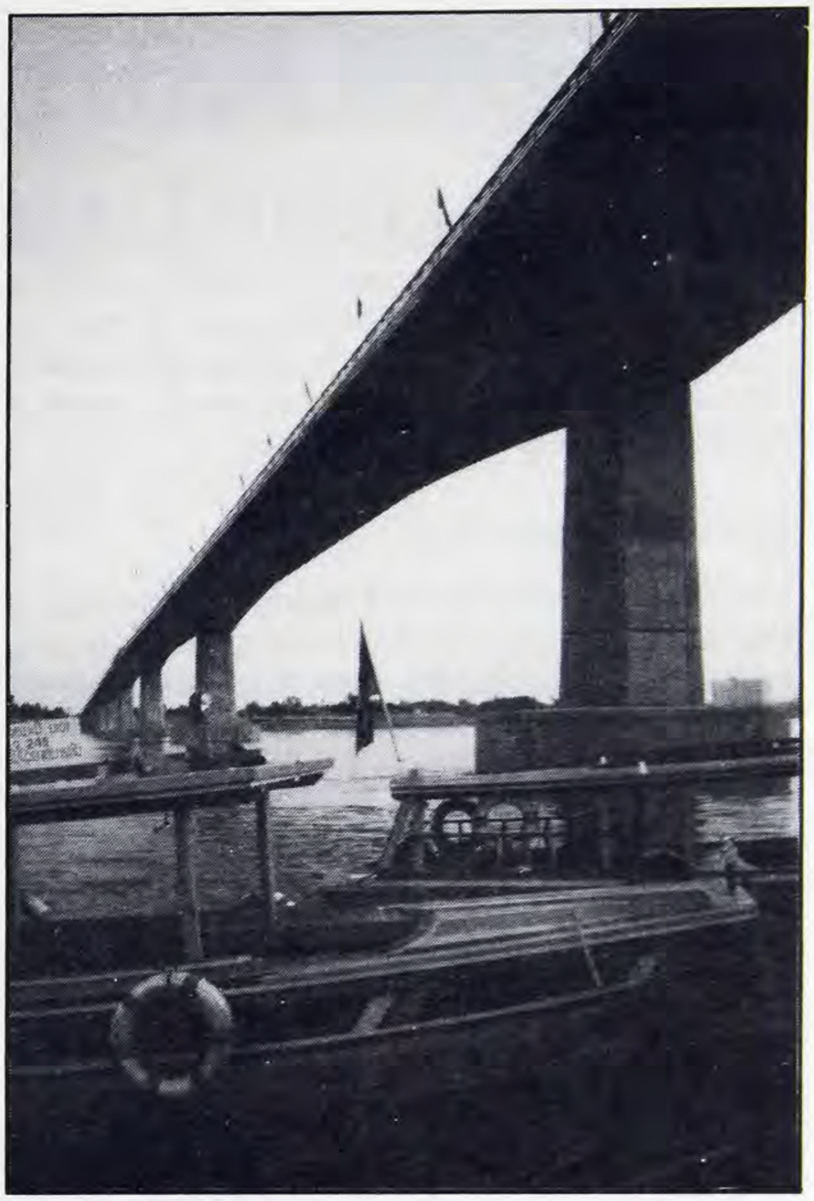
International zone

Because it straddles an international border, the customs and immigration requirements of each country had to be respected, without compromising the effective working of the project. To achieve this, there were lengthy discussions between the three countries during the two and a half years prior to letting the contract. It was agreed that there would be a defined international zone within which special arrangements would apply. The import of materials into the zone would be without hindrance from either country, and the later re-export to the country of origin would also be facilitated. Once within the zone, materials could be moved without requiring any customs clearance, and the normal national customs requirements would not apply.

In a similar way, it was agreed that the immigration requirements of each country would not apply once a person was admitted to the zone. Authorised personnel may move around the zone without requiring to be cleared by customs authorities. In addition to this, each country provides a system of border passes whereby accredited personnel can spend up to 24 hours in the other country without requiring special permission, or requiring a visa.

Australian objectives

As an expensive and high profile Australian gift to the area, the Australian government required the project to be an example of Australian technology



The completed bridge

and to incorporate Australian products as far as was practical and cost effective. For this reason tendering for the project was restricted to bona fide Australian contractors, and the contractor was required to carry out specified major components of the project using his own Australian staff. There was also a requirement that certain materials had to be purchased from Australia, in particular the reinforcing and prestressing steel, the prestressing hardware, the bearings and the roadway expansion joints.

Equality of input from Thailand and Laos

Because the bridge is a joint project which straddles the frontier, and because Australia is funding the bridge equally from its Thai and its Lao aid budgets, it was important that the input from the two countries be approximately equal. At the same time it was essential that the project be run efficiently, and for this reason, work that was to apply to both sides of the river, such as the supply of precast concrete piles, or the manufacture of bridge segments, had to be able to be undertaken in one country and applied to the whole bridge. It was most important that the two countries should cooperate to build a joint project efficiently and economically.

It would have been inappropriate to define how the contractor was to achieve approximate equality of input from the two countries, but it was an important consideration in the assessment of the tenders, and the tenderers were made aware of this requirement from the outset.

Technology transfer

Lao and Thai counterpart engineers working on the bridge are part of the exchange of skills and technology the project has fostered. Four engineers from each country have been attached to either the Maunsell Sinclair Knight Joint Venture or John Holland Constructions to gain practical experience in modern concrete bridge construction, with some travelling to Australia to assist with the bridge's design work.

CONCLUSION

The completed Friendship Bridge demonstrates the forethought, planning and technical capabilities of Australian engineering companies to fulfil client requirements and needs. It stands now as a symbol of Australia's active interest and involvement in South East Asia.■

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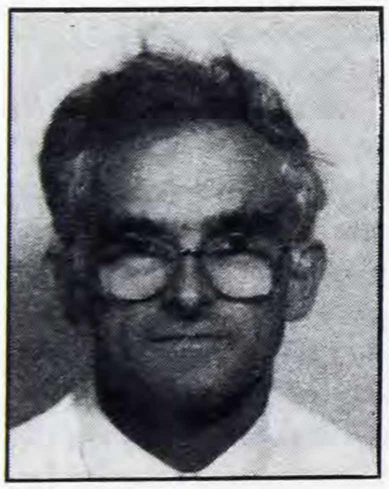

Peter Selby Smith

Peter Selby Smith, Maunsell's Director - Structures, was Project Manager for the Maunsell-Sinclair Knight joint venture during the design and construction phases of the Mekong River Bridge Project. Since joining Maunsell in 1977, he has been Project Manager for many bridge projects including the Echuca Rail Bridge, the James Harrison Bridge in Geelong and the proof check of the Westgate Freeway. Prior to joining Maunsell, Peter worked with a number of construction contractors including John Holland, Polensky und Zöllner (in West Germany) and Cleveland Bridge (in the UK).

Contact: *Mr Peter Selby Smith*
Maunsell Pty Ltd
9th Floor
161 Collins Street
Melbourne 3000