

## STRENGTHENING OF BRIDGES USING EXTERNAL POST-TENSIONING

Ir WAWAN Witarnawan  
Institute of Road Engineering  
Bandung  
West Java  
Indonesia

Dr Albert F DALY  
Transport Research Laboratory  
Crowthorne  
Berks  
UK

abstract: The use of external post-tensioning for the strengthening of existing bridges has been used in many countries since the 1950s and has been found to provide an efficient and economic solution for a wide range of bridge types and conditions. The technique is growing in popularity because of the speed of construction and the minimal disruption to traffic flow. In spite of its widespread use and obvious advantages, there is a lack of general information on how the technique can be applied and there are no specific guidelines available on this method of strengthening. The aim of this paper is to describe the method of external post-tensioning as a means for strengthening bridges which have been found to be under-strength. The paper is based on research projects carried out at the Institute of Road Engineering (IRE), Indonesia, and the Transport Research Laboratory (TRL), UK. Case studies of the strengthening of two bridges in Indonesia are presented as examples of how the technique can be applied to existing bridges.

### 1 INTRODUCTION

The use of external prestressing as a means of strengthening or rehabilitating existing bridges has been used in many countries and has been found to provide an efficient and economic solution for a wide range of bridge types and conditions. The technique is growing in popularity because of the speed of installation and the minimal disruption to traffic flow which can, in many cases, be the critical factor in decisions regarding strengthening. In spite of its obvious advantages, there is a lack of general information on how it can be applied and there are no specific guidelines available on this method of strengthening.

The aim of this paper is to describe the method of external post-tensioning as a means of rehabilitating bridges which have been found to be under-strength. This is the subject of a continuing project being carried out by IRE on methods of bridge strengthening. A similar project is being carried out at TRL which is funded by the Department of Transport and will result in specific guidance for the use of external post-tensioning as a method of strengthening bridges. The method has particular application to Indonesia, where there is a large number of under-strength bridges and where rehabilitation is

required without disruption to traffic.

In the IRE research, laboratory tests were first carried out to determine the effectiveness of the technique and the practical problems of installation. Subsequently, three bridges (steel beam bridges with reinforced concrete decks) have been strengthened and plans to strengthen a reinforced concrete bridge are currently being prepared. The paper presents the principles of external post-tensioning, the conclusions of the laboratory studies, and presents the full scale strengthening of two bridges, Condet bridge in Jakarta, and Kemlaka Gede bridge near Cirebon, are presented as case studies. Included in the paper is a description of the detailing used for anchorages and deviators, the stressing technique, corrosion protection requirements, and the subsequent performance of the bridge.

## **2 BRIDGE STRENGTHENING**

### **2.1 Need for strengthening**

In response to the demand for faster and more efficient transportation systems, there has been a steady increase in the weight and volume of traffic using national highway systems throughout the world. As well as increases in legal vehicle loads, the over-loading of vehicles is a common problem and this must also be considered when designing or assessing bridges. In response to increased traffic flow, bridge widening is often carried out to increase the capacity of the road network. As a result, many bridges are now required to carry loads significantly greater than their original design loads.

This trend is very pronounced in developing countries such as Indonesia as a result of the accelerated regional development which has taken place over the last two decades. In many areas, the road system provides the only means of transporting goods and people and is vital for the survival and prosperity of whole regions. Minor roads which were originally constructed for light traffic are now required to provide access for modern heavy goods vehicles and roads are continuously being up-graded to cope with the increased demands. Bridges are a critical part of this re-classification.

Even bridges which have been designed using appropriate loading specifications can be under-strength for other reasons. Bad detailing, other design faults, and general wear and tear can impair structural performance. Deterioration of bridges due to steel corrosion, corrosion of reinforcement, attack by chemicals or pollution, impact damage from vehicles, all lead to loss of strength. Loss of prestress due to creep and relaxation also results in strength loss. Again, these problems can be accentuated in developing countries where bridge maintenance is often neglected, deterioration rates can be higher due to high temperatures, high humidity and pollution, and the quality of site practice may be low.

Many bridges which were designed to previous loading specifications or which have suffered damage or deterioration are now inadequate for modern heavy goods vehicles. As a result, bridge owners and manager are faced with the choice of restricting traffic or carry out rehabilitation. When this is combined with the growing competition for the funding of infrastructure projects, there is great pressure to keep bridges in service and minimising capital and maintenance expenditure. Bridge strengthening as an alternative to complete replacement can provide an effective and economic solution in appropriate



situations. In particular, traffic management costs can be considerably reduced especially in cases where rehabilitation can be scheduled to avoid complete closure of the carriageway.

## **2.2 Selection of appropriate strengthening technique**

The selection of an appropriate method for strengthening a particular bridge depends on a number of factors. The type of structure, the magnitude of the strength increase required and the associated costs are the main parameters to be considered. Many strengthening schemes are applicable to particular structural types and have limits on the extent to which strength can be increased. Strengthening costs would certainly be lower than bridge replacement, but the selection of a particular method of strengthening would need to be justified on economic grounds. It is important to consider, not only the initial capital costs of the strengthening project, but also the maintenance costs associated with the future in-service behaviour. The condition of the existing bridge is an important consideration. If the bridge is in bad condition, then future maintenance and safety problems might override the benefits of the reduced capital costs of strengthening and provide justification for bridge replacement. The strength and condition of the sub-structure must not be ignored and strengthening should not proceed without giving due consideration to the capacity of the bridge piers, abutments and foundations. The difficulties associated with traffic management and the costs arising from traffic delays should be considered in the economic justification. In some cases, this may limit the use of certain methods of strengthening.

Depending on the bridge configuration and the expected service life of the bridge after strengthening, other factors might need to be considered before a particular scheme is adopted. The durability, inspectability and replaceability of components of the rehabilitated bridge are very important aspects. For some strengthening systems, the ability to monitor the behaviour of the strengthened bridge might need to be considered, particularly where an innovative method is being used. The ability to adjust the level of strengthening in future to allow for further increases in traffic loads might provide useful benefits.

The appearance of the bridge after strengthening is an important consideration and should not be ignored. While bridge aesthetics have always played an important role in the design of major structures, public perception has often been ignored for short span bridges. This is now beginning to change and emphasis is now being placed on how highway bridges look. The use of intermediate supports or props, or strengthening methods which appear unsightly, while tolerable as temporary measures, are becoming less acceptable as long term solutions.

Many strengthening techniques have general applicability, but some may be specific to particular bridge types and configurations. The decision to adopt a particular scheme is based on the consideration of a wide range of parameters. The remainder of this paper is concerned with external post-tensioning for bridge strengthening. The general principles, advantages and disadvantages are described in the following sections.

### 3 APPLICATION OF EXTERNAL POST-TENSIONING

#### 3.1 General

The principle of external post-tensioning is the same as that of prestressing, ie, the application of an axial load combined with a hogging bending moment to increase the flexural capacity of a beam and improves the cracking performance. It can also have a beneficial effect on shear capacity. Precise evaluation of flexural and shear capacity of beams with unbonded tendons, either internal or external to the section, is difficult. This is because the load in the tendons is a function of the overall behaviour of the beam, rather than just depending on the strain distribution at a particular critical section. Many national and international codes present methods of determining capacity but these are based primarily on laboratory results obtained from tests on beams with internal tendons.

Post-tensioning as a means of strengthening existing bridges has been in use since the 1950s and there are many examples of its use throughout the world. In the many situations where the technique has been applied, the prestress is applied through prestressing cables, either single or grouped strand. In some applications, the stress has been applied through high tensile bars, jacked either using hydraulic jacks or with fine screw threads. In a few cases the stress is applied using more unconventional techniques. For example, stress in a tendon can be developed by anchoring a straight the tendon in place and imposing a deflection at mid-span. The deflection is then retained by fixing the deflected point. Prestress can also be developed by applying a load to the structure to cause overall deflection prior to anchoring the tendons or bars. Specific examples of these different applications are given by Xanthakos (1996).

External post-tensioning can be used to improve the serviceability behaviour of existing bridges. As in prestressed construction, the method can be used to delay or prevent the onset of cracking in concrete bridge decks. It can also be used to reduce or close pre-existing cracks. This improvement in cracking behaviour also increases resistance to reinforcement corrosion. The increased stiffness provided by external post-tensioning can reduce in-service deflections and vibrations. The stress range can also be reduced and the fatigue performance can be improved. The presence of a deformation or sag in a bridge can be reduced or removed.

#### 3.2 Application to beam type bridges

External post-tensioning as been applied most generally to beam type bridges. The tendons can be straight or draped using deviators depending on the particular requirements. Various profiles can be adopted to suit the required combination of axial load and bending. Additional compressive members can be introduced if the additional compression stressed imposed on the beam are not desirable.

External post-tensioning can be used to improve the performance of any kind of beam bridge, be it timber, reinforced concrete, prestressed concrete, steel or composite. The main reason for its use has been to provide increased flexural strength required because of under-design, increased traffic loading, loss of structural strength due to deterioration or to correct serviceability problems. In particular, the application to prestressed beams is appropriate where losses in initial prestress due to creep, relaxation or corrosion can be restored. The technique can also be used to increased the shear strength although vertical



prestress, described later, can be more appropriate in correcting shear deficiencies.

It is possible to use post-tensioning to change the structural behaviour in order to increase strength. For example, the strengthening object might be to provide continuity across a support, ie, change a series of simply supported spans to a continuous one. It can also be used to provide continuity across an unsupported joint, for example, across the joint between two cantilever spans.

### **3.3 Application to slab bridges**

There have been no reported cases of solid or voided slab bridges being strengthened using external post-tensioning. It may be possible where the deck is narrow and the tendons could be installed on both sides of the slab. The technique could be used to replace prestress loss in prestressed slabs where, for example, corrosion has taken place. The main difficulty would be in accommodating the anchorages and fixing them to the existing slab.

### **3.4 Application to truss bridges**

The technique of post-tensioning has been applied to steel truss bridges since the 1950s and various configurations have been used. Individual members can be strengthened by applying concentric prestress on highly-stressed tensile members. Groups of members can also be post-tensioned in the same way. For example, the tension chord can be stressed with a single long concentric cable. This was carried out on a number of rail bridges in the UK in the 1950s (Lee 1952).

A truss bridge can be strengthened by applying a polygon tendon to the truss as a unit. The cable is fixed to the top of the truss at the supports, sloping down to the bottom of the truss at mid-span. This method was used to strengthen a steel truss bridge in Switzerland in 1969 (Xanthakos 1996). Because the upper chord was not strong enough to carry the induced compression, an additional strut was required along the top members.

It is also possible to strengthen a truss using a draped tendon along the bottom chord. No such cases have yet been reported.

### **3.5 Transverse post-tensioning**

External post-tensioning can also be used in the transverse direction to improve load distribution across the deck or to increase the transverse stiffness. The method can be convenient for replacing conventional transverse prestress lost due to creep or corrosion. The same post-tensioning techniques are applicable.

The technique can also be used to repair arch bridges which have developed cracks in the spandrel walls due to lateral pressure through the fill material (Xanthakos 1996).

### **3.6 Vertical post-tensioning**

Longitudinal or draped tendons can be used to improve the shear capacity of beams. Where flexure is not a problem but a significant improvement in shear strength is required, the application of vertical might provide an effective solution. Vertical prestressing tendons or bars can be applied to the web of an I-beam. For concrete box sections, they can be installed either inside or outside the box. Because of the short length required, the

post-tension force can most easily be provided using high strength bars with the required prestress produced using fine threads.

Vertical prestress can also be used to provide tie-down at supports. This can be very useful in earthquake regions where lifting forces might occur, as the tie-down can be retro-fitted to existing bridges. This technique can also be used to improve defective joints.

### 3.7 Advantages and disadvantages

As with all bridge strengthening methods, there are various advantages and disadvantages associated with the use of external post-tensioning. There are a number of distinct advantages which have added to the increasing popularity of this method. These are listed as follows:

- The method is economic in that it cheaper to install than methods which require major reconstruction of the bridge deck. The equipment required, while specialist in nature, is light and easy to use, particularly when single strand jacks are employed. Anchorages and deviators are easy to detail and simple to install.
- Both flexural and shear strength can be increased without the penalty of increased dead load.
- The ease of inspection increases the reliability of the bridge as any stress loss or damage due to impact or corrosion can be determined by simple inspection procedures.
- The tendons can be re-stressed provided sufficient length of tendon is left behind the anchorage, sufficient access is made available to enable the re-fitting of the stressing jacks and a flexible corrosion protection material is used, ie, wax or grease. Re-stressing can be carried out with minimal disruption to traffic, provided account is taken of the reduced strength when the stress in a tendon is reduced. Thus any stress losses due to creep, relaxation, corrosion, etc, can be replaced. The stress magnitude can also be increased to allow for future additional strengthening. The use of single strand jacks greatly reduces the effort involved but the twisting of strands in a cable group should be avoided if single strands are to be re-stressed. Re-stressing can also be used to determine the residual load in the strand.
- The tendons can be made fully replaceable, as described above. The tendons can be removed to carry out a close examination. If corrosion or any other damage is detected a new tendon can be installed.
- Where grout is used inside a duct to provide corrosion protection, individual strands cannot be re-stressed or replaced. However, the tendon can be removed by cutting the tendons and replacing the tendon-duct system. For this reason the use of grout is not generally recommended, except in localised areas.
- Many strengthening methods cannot be applied to an in-service bridge because of the vibrations or because of access. With external post-tensioning, the strengthening of a bridge can be carried out without disruption to traffic flows on the bridge. No



traffic restrictions are required on the bridge being strengthened other than those already applied to the unstrengthened bridge. Where the bridge is road over road, traffic restrictions would be required on the road under the bridge for access. For box girder bridges where access is through the abutment, no closures would be required.

- Tendons can be draped to increase eccentricity where required. Eccentricity can be increased by installing the tendons below the bottom flange.
- The friction losses associated with external tendons are considerably less than those for internal tendons. This means that the tendons can be longer and the deviation angles greater than with internal tendons.
- For box girder bridges, the tendons can be installed inside the box, so that they are not visibly intrusive.
- A number of methods of corrosion protection are available. It is also possible to have multiple levels of protection, eg, inside a box, inside a ducts, wax. These methods are generally easy to install although there are detailing problems at anchorages and possibly at deviators.

As with other methods of strengthening, there are disadvantages and it is important that these be understood in order to make an enlightened evaluation of this method. The main disadvantages are as follows:

- Application of the method is very dependent on the existing condition of the bridge. Concrete of poor quality should not be over-stressed and a full condition survey should be carried out to ensure that the bridge deck can take the increased stress. Where the condition of the concrete is suspect, due to corrosion, deterioration, impact damage, etc, the post-tensioning should be applied with care.
- Loss of stress due to creep and relaxation are an inherent part of post-tensioning and should be taken into account in both steel and concrete beams. This disadvantage is negated to a certain extent because of the ability to re-stress the tendons.
- Installation of deviators and anchorages can be difficult, and careful detailing is required to account for stress concentrations in the existing deck components. Normally, drilling through or welding existing structural components to steel webs, concrete webs, flanges, etc, is required. This can be problematic, particularly since the bridge deck is already under-strength. However, these can normally be installed in less critical areas. Local stiffeners may be required at anchorages and deviators.
- The tendons, being external, are more susceptible to corrosion, and often need to be placed in areas of run-off, eg, near joints. The tendons can be susceptible to contamination by bird and bat droppings, eg, inside boxes, along beams. Cases where tendons have been submerged during floods have been reported. Effective corrosion protection is critical to the effective performance of this method. Standard methods are available.

- The shear capacity of beams with external tendons is difficult to determine. Conservative methods are available but the degree of conservatism is at present unknown. Further research is required in this area.
- For shear, strengthening near supports, normally the critical area for shear, is difficult because of access difficulties. For these reasons, the method has been generally confined to flexural strengthening.
- The effects of axial load may be detrimental to the carrying capacity and needs careful consideration. Where this is the case, increasing the eccentricity of the tendons can increase the prestress without a corresponding increase in axial load.
- The ductility of concrete beams post-tensioned with external tendons is still questionable. This is because, since the tendons will never reach yield, failure will be due to concrete compression in the top flange. However, in the few laboratory tests carried out at TRL, externally post-tensioned beams failed after large deflections and with significant residual strength after failure. The behaviour of steel beams post-tensioned with external tendons has not been investigated in detail.
- Installation of the tendons can mean working in difficult conditions and confined spaces, eg, on abutment shelves, inside boxes, on scaffolding, etc. The hardship is minimised by single strand jacks and modern access equipment.
- Where tendons need to be installed below the bottom flange, the decreased headroom is a distinct disadvantage. This may be critical, in railway bridges for example, and may be a sufficient reason for adopting an alternative strengthening method. If the bridge is road over road, the tendons can be damaged by high vehicles passing under bridge. The method should only be adopted if there is sufficient clearance to ensure that this is an unlikely event.
- The appearance of the external cabling system might discourage their use, particularly when the tendons are installed below the soffit of the beams. Care in the detailing and lay-out can assist in blending the strengthening system in with the existing structure. If required, the tendons can be enclosed using panels: this would also help in providing some protection against corrosion or contamination. Where the tendons are installed inside boxes or along the webs of beams, there is little or no visual intrusion.
- The external tendons, as in all cable stayed structures, are more susceptible to accidental damage from fire, impact and acts of vandalism and public access to the tendons should be prevented. However, this type of damage will only impair the strengthening system: the resistance of the existing bridge is not altered so the likelihood of collapse is not increased.
- For proper installation of external tendons, precise fabrication, accurate installation and careful site supervision and inspection are required. The stressing sequence and schedule needs to be devised carefully to avoid damaging the existing deck.



- Because additional stress is being introduced into an under-strength structure, careful and accurate analysis is required in devising the tendon configuration. A proper understanding and accurate estimation of the stress distribution in the deck is required for the future safety and stability of the bridge. This might require additional special investigations, eg, determination of the existing stress in a prestressed bridge.

The conclusion is that the method of external post-tensioning as a method of strengthening existing bridges has both advantages and disadvantages. Careful consideration is required before an effective strengthening system can be devised. The recent collapse of the Koror-Babeldaob bridge in Palau near the Philippines shortly after it was strengthened using this method indicates the importance of such considerations (NCE 1996).

#### 4 Case study I: Condet bridge

##### 4.1 Description of bridge

Condet bridge is a heavily-trafficked composite bridge on the 4-lane road between Jakarta and Citarum which carries up to 30,000 vehicle per day with a large percentage of heavy trucks. It has three spans of 24m, 48m and 24m. The bridge is shown in elevation in Figure 1. The bridge was built in 1989, designed for full Indonesian Highway loading, but after five years of service strengthening was required. External prestressing was

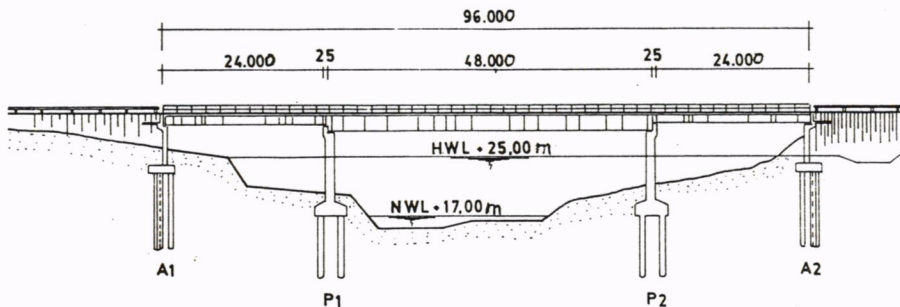


Figure 1 Elevation of Condet bridge.

applied in 1994 to rehabilitate the bridge to enable it to carry full design loading.

The original bridge had a "pre-compressed" deck. Each span consisted of a series of ten steel beams and an in-situ reinforced concrete slab. The slab was cast in two segments with a space between the segments at mid-span. The slab segments were connected to the beams at the supports with reinforcement acting as anchor bars, as shown in Figure 2. When the slab segments were cast, flat-jacks were inserted into the space at mid-spans and a force applied which induced compression in the concrete and hogging moment in the steel beams. Before the flat-jacks were removed the space was filled with a high strength concrete plug to maintain the pre-compression. Shear connectors along the beam, which were prevented from bonding to the concrete during casting by the use of void formers, were then grouted in to ensure composite action.

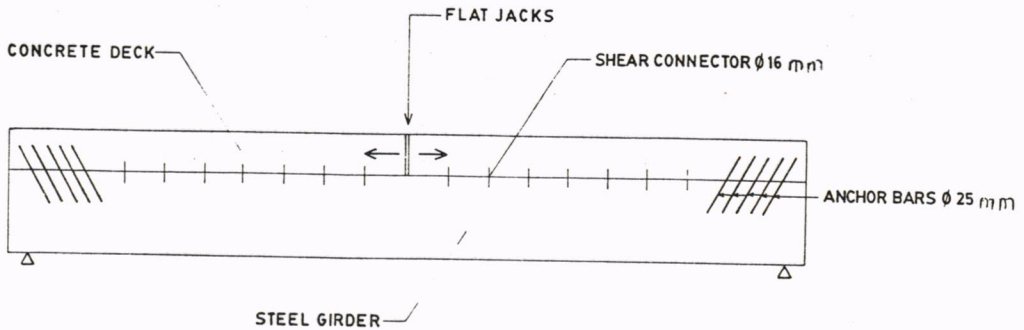


Figure 2 Method of pre-compression as used in Condet bridge.

#### 4.2 Need for strengthening

After five years of service, openings were observed in the joints between the concrete plugs and the in-situ slab. A survey of the bridge deck indicated that permanent sags of 65mm, 115mm and 78mm had occurred in the three spans respectively since the bridge was constructed. In addition, vibration from traffic had become inconvenient to pedestrians and drivers using the bridge. A load test was carried out to determine the behaviour of the deck under vehicle loading. Strain gauges were placed at mid-span at three composite section to determine the stress distribution. The results indicated that the bridge was not acting compositely, with separate neutral axes in the concrete and steel sections. Examples of some the results are shown in Figure 3. It was clear that the pre-compression was not being maintained in the deck. This was attributed to shrinkage and

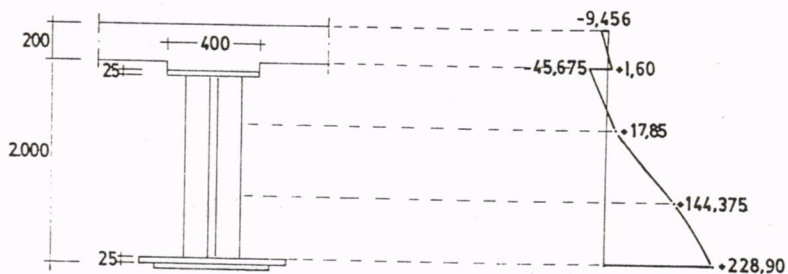


Figure 3 Distribution of stress ( $\text{kg}/\text{cm}^2$ ) before strengthening.

creep in the concrete slab. As a result, it was calculated that the capacity of the bridge was reduced by 35%.

As the bridge carried a high volume of traffic along a major route, immediate strengthening was required with minimal disruption to traffic. The following methods of strengthening were considered:

- Re-compression of the deck by re-installing flat-jacks and replacing the concrete plugs;



- Installation of steel trusses under each of the steel beams;
- Application of external tendons to stiffen the deck and replace prestress force.

Re-compression of the deck would return the bridge to its original form without the need for any additional structural components. However, access across the full deck would be required to remove the concrete plugs, install and re-stress flat-jacks, insert and cure new concrete plugs and make good the deck. This would entail extensive carriageway closures. Other costs would be incurred because of patent rights. In addition, it is likely that the work would have to be repeated after about five years because of continuing concrete creep.

The installation of strengthening trusses under the deck could be carried out at moderate cost and no major closures of the bridge would be required. However, the erection of the trusses would be time-consuming, extensive scaffolding and other temporary supports would be required in the river under the bridge, and the trusses would add significant dead weight to the deck.

External post-tensioning was chosen as the preferred method of strengthening because of the minimal disruption to traffic, the low weight of the additional components, the speed and short duration of construction, and the low costs involved. In addition, future re-stressing operations could be carried out quickly and conveniently, if required.

#### 4.3 Strengthening details

Figure 4 shows a schematic lay-out of the strengthening scheme used in each of the three spans. Each beam was strengthened using two cables, consisting of three 12.7mm high

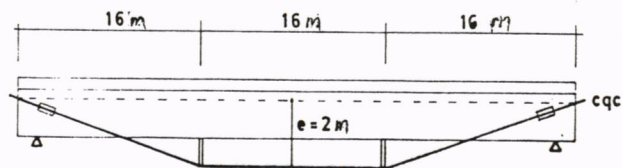


Figure 4 Schematic view of cable arrangement in span of Condet bridge.

strength strands placed at an eccentricity of 2m over the middle third of the span. Each 7-wire strand, supplied by VSL, was greased and individually sheathed in a polyethylene tube to provide protection against corrosion. The tendons were anchored near the support using specially fabricated anchor plates. Details of the anchorages are shown in Figure 5. All plates were 20mm thick. The strands were anchored using standard VSL barrels and wedges. The anchorage plates were installed using 9 No 16mm diameter bolts and fixed permanently in place by welding. At the anchorages, the sheathing was removed from the strand for sufficient length to enable the wedges and stressing equipment to be installed. To reinstate the corrosion protection, a steel box was fabricated around the anchorage after stressing, fully enclosing the barrels and wedges. This was then filled with grease. Where the tendons protruded from the box, a steel pipe filled with grease was placed over the strands. All exposed parts of the strand and all joints in the sheathing were then

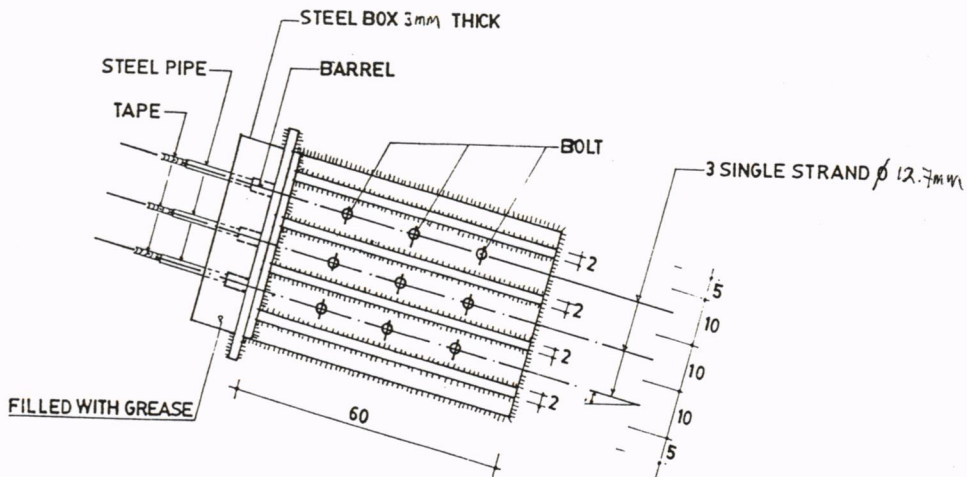
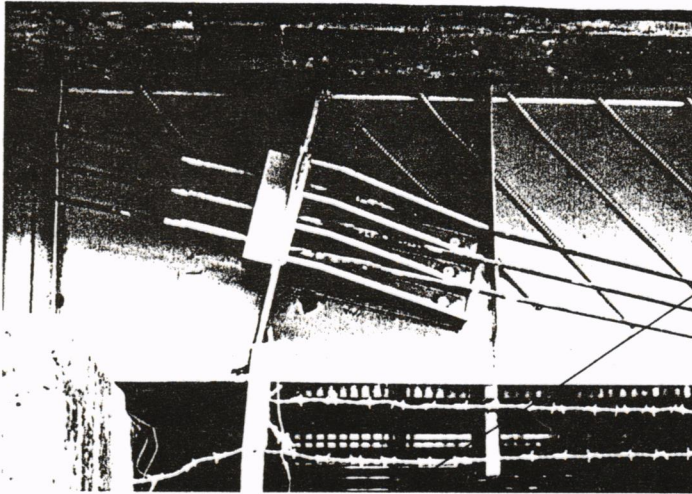


Figure 5 Anchorage used in Condet bridge.

covered with greased tape to seal the system completely.

The deviators were fabricated from standard I-beams, 600mm deep with a 300mm wide flange, as shown in Figure 6. Deviation was devised by passing the group of three strands through a steel pipe 50mm in diameter which was welded to the supporting components. A piece of polyethylene pipe was placed inside the deviator to protect the tendon. The sheath was continuous through the deviator.

Additional cover plates, thickness 15mm, were installed on the underside of the top flange of the steel beams for a length of 1.6m at the deviator locations to provide local strengthening. Stiffeners were also installed at the deviator locations to prevent high stress concentrations and local buckling.

Figure 7 shows the underside of Condet bridge after strengthening. A similar lay-out was



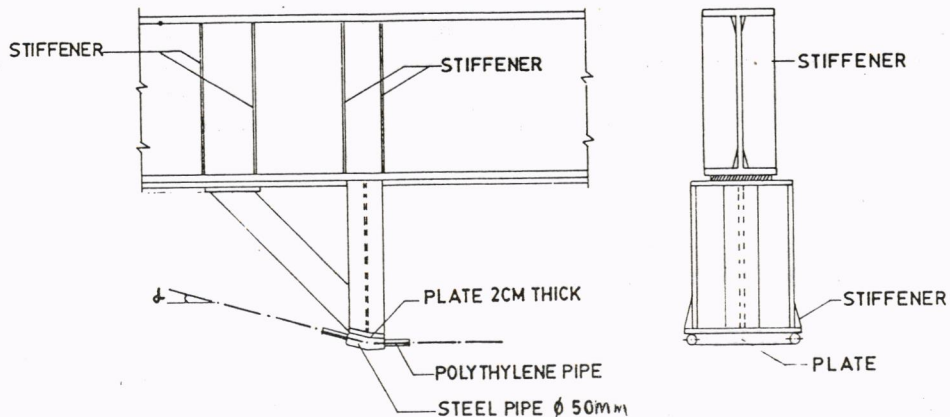


Figure 6 Deviator used in Condet bridge.

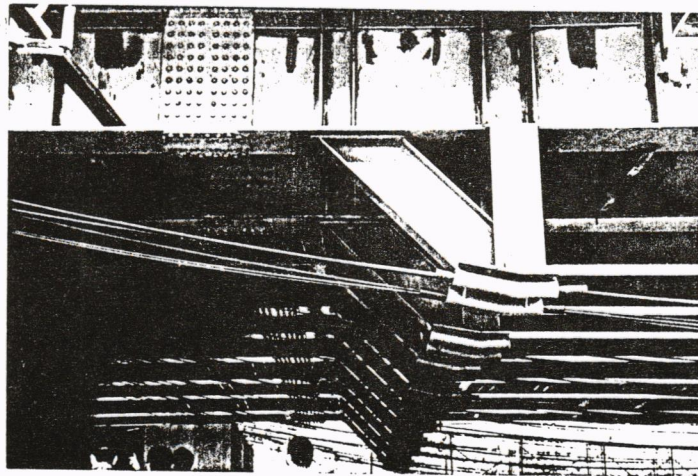


Figure 7 General view of underside of Condet bridge after strengthening.

devised for each of the side spans. Tensioning of the cables was carried out in stages to prevent excessive differential movement of the beams which might cause longitudinal cracking in the deck concrete. The design prestress force was 13.1 tonnes per strand. This was applied in four stages, using a light single strand hydraulic jack. The behaviour of the bridge during stressing was monitored so that over-stressing and damage could be detected. After installation of the entire strengthening system, the bridge deck at mid-span moved up by 52mm.

#### 4.4 Concluding remarks

Recent inspection of the bridge revealed that the bridge is functioning in a satisfactory manner and the strengthening system is in good condition. In 1995, exceptionally high

floods occurred and all the tendons were submerged. This was unexpected and not considered during design, as the tendons are about 6m above normal water levels. To date, no detailed inspection has been carried out to determine whether any corrosion damage problems might occur as a result of this or future re-occurrence. In spite of this, the tendons, anchorages and deviators appear to be in good condition based on superficial inspection.

## 5 Case study II: Kemlaka Gede bridge

### 5.1 Description of bridge

Kemlaka Gede bridge, shown in elevation in Figure 8, is on the main east-west link on the island of Java. This road is heavily trafficked, carrying about 40,000 vehicles per day

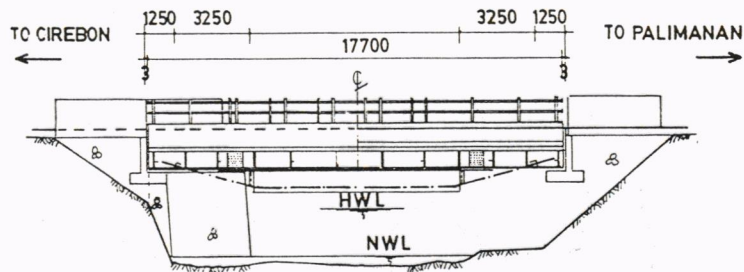


Figure 8 Elevation of Kemlaka Gede bridge.

along the east-west link on the island of Java. The bridge is a single span bridge, 17.7m in length, carrying a 7.56m wide carriageway. The deck consists of five steel beams at 2m spacing with an in-site cast reinforced concrete composite deck. The bridge was built in 1973 and was strengthened in 1995 to enable it to carry the current traffic requirements.

The beams consists of stiffened plate girders connected transversely with steel channel sections bolted to plates which are welded to the webs. The beams are I-beams, 710mm deep with flanges 300mm wide. The plate thickness is 30mm for the flanges and 20mm for the webs. Joints in the beams are made using rivetted plates. Details of the shear keys between the beams and the deck are not known. The beams bear onto steel sliding plates which are supported by concrete abutments.

### 5.2 Need for strengthening

Every 5 years since the bridge was built, the road has been over-layed with 50mm of additional asphalt. In 1994, the thickness of the surfacing had increased to 300mm compared with the original design which assumed 70mm of surfacing. As a result, the dead load increased by approximately 0.5 tonnes/m<sup>2</sup>. This significantly reduces the live load capacity of the bridge, from a uniformly distributed load of 0.8 tonnes/m<sup>2</sup> to 0.3 tonnes/m<sup>2</sup>. Because of the bridge and road configuration, it was not possible to remove the surplus surfacing from the bridge. The use of external post-tensioning as the preferred method of strengthening was selected for the same reasons as for Condet bridge.



### 5.3 Strengthening details

The purpose of the strengthening was to increase the capacity of bridge to full highway loading so that no traffic restrictions are required. The strengthening details used for this bridge were generally similar to those of Condet bridge as described above. For Kemlaka, each beam was strengthened using two cables, each consisting of two 7-wire VSL strands, 12.7mm in diameter.

Details of the anchorages used on Kemlaka Gede bridge are shown in Figure 9. These were initially bolted to the webs of the original plate girders and then welded permanently.

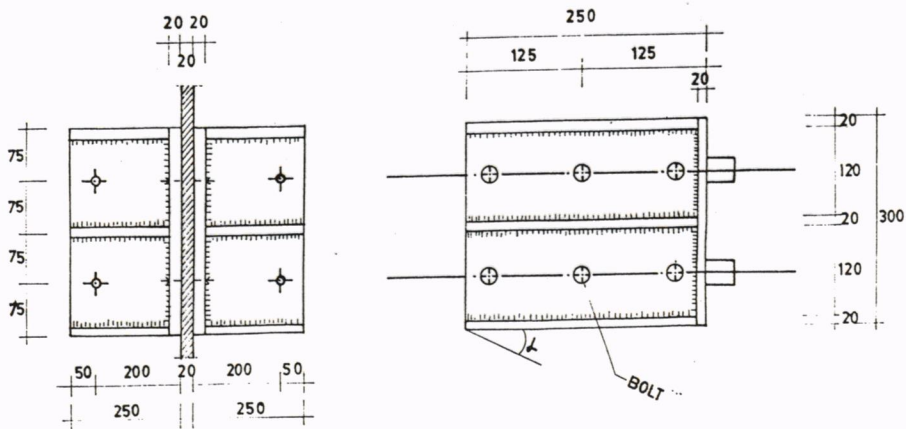


Figure 9 Anchorage used in Kemlaka Gede bridge.

The deviators, shown in Figure 10, were fabricated from I-sections 300mm deep with 150mm flanges. The deviator tubes consist of two lengths of 50mm diameter pipe welded

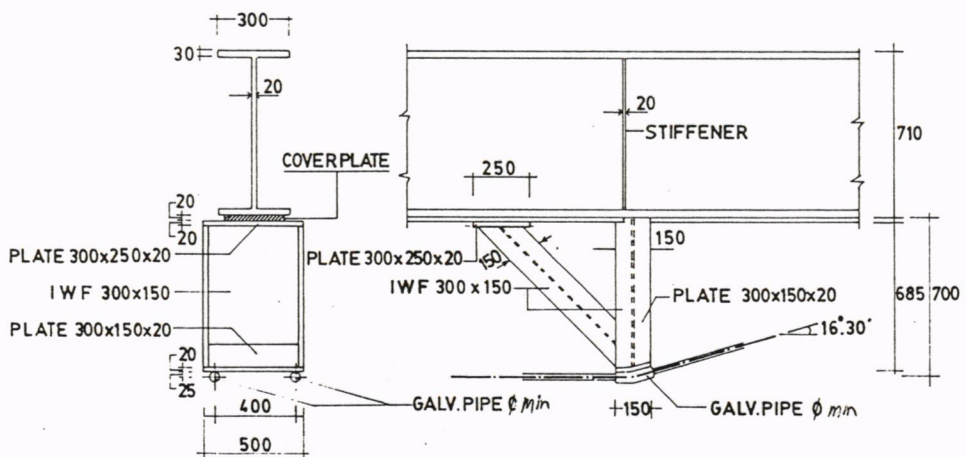


Figure 10 Deviator used in Kemlaka Gede bridge.

together. The sheathed tendons pass freely through the tube with no additional corrosion protection other than that provided by the continuous sheath. Figure 11 shows a general view of Kemlaka Gede bridge after strengthening.

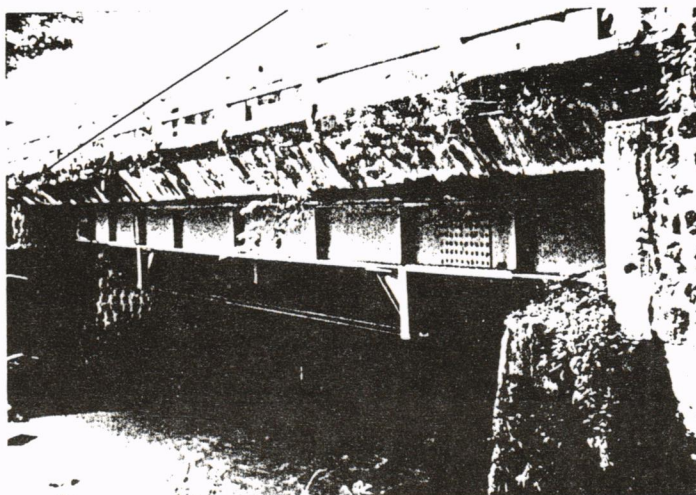


Figure 11 General view of Kemlaka Gede bridge after strengthening.

#### 5.4 Concluding remarks

Load tests were carried out before and after strengthening. These indicated that the mid-span stresses in the steel beams were reduced by 30% to 50% showing that the strengthening was effective. After three years, the bridge is performing adequately but there are problems of corrosion in the strengthening system. The tendons are sheathed, but the sheath was removed at the anchorages. No supplementary corrosion protection was provided here and surface corrosion is evident on all exposed tendons. It is not clear why the tendons were left unprotected in these critical locations as they were at Condet bridge. In addition, the end of the sheath which is cut off before the anchorage is not sealed and it is likely that it is not providing any protection. In fact, it may be serving as a water trap, allowing water to leak along the tendon to the deviator. It is likely that all tendons will require replacement in the near future.

#### 6 Conclusions

Modern conditions and constraints require that effective methods for the strengthening of existing bridges need to be developed. In particular, effective methods which can be applied with minimal disruption to traffic and which are inexpensive and easy to install, are required. External post-tensioning satisfied these requirements. This method has been used for bridge strengthening since the 1950s, but there is currently no specific guidelines on how the technique can be applied in the field.



The principles of external post-tensioning have been described and the advantages and disadvantages discussed. Two case studies have been presented as examples of how the technique can be applied to under-strength bridges. The experience of external post-tensioning in Indonesia suggests that this is a convenient and economic method for bridge strengthening.

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