REHABILITATION OF STEEL BRIDGES IN SRI LANKA

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ABSTRACT

Nearly one half of the approximately 3700 highway bridges on A and B class roads of Sri Lanka are more than 50 years old. About 60% of the total bridges have a width of less than 8.0 m; out of these 689 are steel bridges. Most of these steel bridges would need upgrading in future to cater for present day traffic needs. The upgrading option can be either replacement or rehabilitation. Rehabilitation can be quite attractive if it can have cost savings and fewer disturbances to traffic. In this paper, various options available for rehabilitation of steel bridges arc reviewed. The methods better suited for Sri Lanka arc identified. The criteria to determine the economic feasibility arc highlighted. The anticipated cost of replacement is determined to indicate the importance of adopting rehabilitation whenever cost effective.

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ABSTRACT

Nearly one half of the approximately 3700 highway bridges on A and B class roads of Sri Lanka are more than 50 years old. About 60% of the total bridges have a width of less than 8.0 m; out of these 689 are steel bridges. Most of these steel bridges would need upgrading in future to cater for present day traffic needs. The upgrading option can be either replacement or rehabilitation. Rehabilitation can be quite attractive if it can have cost savings and fewer disturbances to traffic. In this paper, various options available for rehabilitation of steel bridges are reviewed. The methods better suited for Sri Lanka are identified. The criteria to determine the economic feasibility are highlighted. The anticipated cost of replacement is determined to indicate the importance of adopting rehabilitation whenever cost effective.

INTRODUCTION

The majority of steel bridges in Sri Lanka were built in the last 50 to 60 years. Out of a total of 3700 highway bridges (Bridge Database, RDA) on A and B class roads (Figure 1), approximately 60 % of the bridges have a width less than 8.0m. For the present day traffic conditions, a deck width of about 8.0m can be considered as the minimum satisfactory. This can accommodate two lanes of 3.0m each and a walkway of 1.0m on either side. Thus, many bridges can be considered as functionally obsolete when called to cater to the present day traffic requirements. A functionally obsolete bridge is one whose vertical clearance distance from bottom of stringer/ cross beam/ soffit of truss, to roadway or water level below), approach roadway alignment or deck geometry, (available roadway width) no longer safely or comfortably serves the network of which it is an integral part.

Out of the bridges of width less than 8.0m, 689 are steel bridges (Figure1). Majority of old bridges constructed using Steel, Cast Iron and Wrought Iron, have been exposed to the degrading effects of the environment and are in need of structural and geometrical improvements to withstand the higher axle loads of the heavier present day traffic.

The generally adopted practice in Sri Lanka in the case of steel bridges with geometrical or structural deficiencies is to replace them altogether by wider concrete bridges. However no objective assessment criteria has been developed to identify the cost effectiveness of these replacements against the option of rehabilitation, like the much-preferred EUAC number in the AASHTO practice (NCHRP 293, 1987).

This paper highlights the available methods for the strengthening of these bridges as practiced world-over. It also discusses the possibility of adopting them for local bridges, instead of replacing in relation to constructibility and economy. The paper deals only with the superstructure and does not concentrate on the rehabilitation/strengthening of the foundation and substructure. If found necessary those also should be assessed and improved in parallel to complete a project.

OBJECTIVES

The main objectives are the following.

(1) Identification of bridge strengthening methods suitable for Sri Lanka.

(2) Determination of the usefulness of developing bridge strengthening methods for Sri Lanka.

(3) Developing a suitable method for rational decision making in adopting rehabilitation or replacement options.

METHODOLOGY

The following methodology was adopted

(1) A detailed literature review was undertaken to determine the various methods adopted in other countries for strengthening of existing bridges.

(2) The data available with the Road Development Authority of Sri Lanka were analyzed to determine the usefulness of strengthening of existing bridges.

(3) The various criteria available to determine the economic feasibility of strengthening of existing bridges were evaluated.

LOCAL SCENARIO FOR STEEL BRIDGES

The widely adopted structural configurations, in case of motorable steel bridges are the following:

(1) Trussed bridge

(2) Steel beam and concrete composite bridge

(3) Steel beam and steel plate non composite bridge

Most of the steel bridges in Sri Lanka are simply supported spans. A truss bridge usually comprises two parallel trusses or girders supporting the roadway; this may rest either directly upon the upper chords (Deck bridge) or on the lower chords (Through bridge). Short span highway bridges of the through type with trusses not deep enough to permit overhead bracing are known as Pony truss bridges.

The steel beam bridges are constructed by either using rolled steel joists (RSJ) spanning between supports or using plate girders, to support a steel and concrete floor system acting compositely. In the non-composite construction, the usually adopted practice is to span a steel curved or corrugated plate between the steel beams which supports a lean concrete or a bituminous fill to form the road surface.

It is very important to distinguish the exact type and material of the existing structure as originally designed and constructed in deciding on any rehabilitation for such a project to be successful. This is because these factors could have a direct bearing on the particular method to be adopted for the rehabilitation.

STRENGTHENING METHODS FOR STEEL BRIDGES

The required increase in load carrying capacity of various types of bridges can be due to increase in the number of notional lanes or due to increase in the design loads. The different methods used are as follows (NCHRP 293, 1987):

(1) Increasing member cross section,
(2) Adding/Replacing members,
(3) Adding supports or moving the supports,
(4) Providing continuity,
(5) Providing lateral supports or stiffeners,
(6) Applying external post tensioning,
(7) Modifying load paths.

Increasing member cross section

This is generally the most common method of strengthening adopted by various organizations though not documented very often. One possible reason for this could be the belief of the engineers concerned that the method does not warrant documentation due to its frequent application. Increasing the member cross section by the addition of steel plates or rolled sections to either steel beams or to members of steel trusses could be used in a variety of situations. It can be used to increase the section modulus of the member thus reducing the imposed stresses, or to reduce direct stress of a truss member, and to increase the capacity of a compression member, by reducing the slenderness ratio.

Adding/Replacing members

In truss bridges, additional members could be in the form of diagonals to create double diagonal panels or reduce the effective length of compression members (Figure 2a). The addition of an entire truss in deck trusses or using bailey bridges to be inside existing through trusses connected to existing floor system through hangers (Figure 2b) could be another form of the same method. Generally, an addition of a member or a strengthening of a member cross section will only provide relief against the loads added afterwards. However, if dead loads too should be distributed to the new added members, the dead load needs to be relieved of the member initially before the strengthening (Pritchard, 1992). This could be a method that can be adapted to many truss bridges in Sri Lanka.

Adding supports or moving supports

In certain instances, it may become possible to provide an additional support system to enhance the carrying capacity of a bridge. For example, a single span truss bridge could be changed to a 2 span continuous bridge by providing a single pier at the center of the span (Figure 3a). Sometimes, instead of providing an additional support, it may be possible to shift or change the support of a length of a panel in truss bridges (Figure 3b) or it could be converted to a cable stayed bridge by providing a cable system from an additionally constructed center pier (Figure 3c). However, the structure should be fully analyzed for the new structural behavior and strengthened at required locations. This method is only suitable if the addition of support is physically, structurally and economically feasible.

Providing continuity

A simply supported multi span bridge could be made continuous by simply connecting the spans together at the pier points, through moment and shear connections. Care should be exercised to analyze the multi spanned continuous bridge to identify locations, which may require additional strengthening due to reversing of the stresses. This method is well suited for a series of steel stringer bridges, where the moment shear connection could be accomplished easily with high strength bolts and web and cover plates (Figure 4).

Providing Lateral support or stiffness

Transverse stiffening of a deck could adjust the distribution characteristics of a bridge deck to a certain extent. The introduction of additional diaphragms or cross bracing with moment transfer connections as shown in Figure 5, can reduce the global moments of an internal stringer thereby increasing its live load capacity. However, the method does not reduce the moment of the exterior girder appreciably (Bakht & Jaeger, 1985). Thus, the method is mostly applicable to beam and slab bridges, and is not particularly well suited for truss bridges, except in cases where provision of lateral support frames for compression chord of a pony truss. The method is best suited for curved bridges, where addition of diaphragm could reduce the warping stresses considerably (Bakht & Jaeger, 1985).

Applying external Post Tensioning

Fatigue is considered as one of the main causes for failure of steel bridges. Fatigue is confined to the tensile chord and connections of a steel bridge. In connections, the fatigue could be avoided by due consideration to detailing (Iffland & Birnstiel, 1993). Lowering the induced tensile stresses could reduce the probability of fatigue failure of a tensile chord. This could be achieved by providing a global compressive stress on to the tensile chord, through post tensioning. The post tensioning could be achieved through the anchoring of a tensioned high strength steel cable on to the tensile member (Ojah & Chatuvedi, 1978), either concentrically or eccentrically as shown in Figure 6. The additional forces imparted through the post tensioning force should be analyzed (Ito, 1993) and some other members (especially the compression chord) strengthened if found required through a complete analysis of the bridge.

Another aspect in the strengthening procedure is the durability of the strengthening itself. In using post tensioning as a means of strengthening, available literature suggests various new materials, which could be used to obtain the desired durability without sacrificing economy. (Wade et.al, 1993)

Modifying load paths

If a bridge is to be strengthened globally, due to it's overall deficiency, superimposing the bridge with a bailey type bridge (Figure 2b) or providing a supplementary load carrying system could be thought of in order to provide a continuing passage of traffic. A truss bridge could be supplemented by a steel arch bridge with hangers connected to existing floor beams or new floor beams, as shown in Figure 7. The truss shares the load with the arch, while providing lateral stability to the arch. The method obviously could be more expensive than the other methods discussed so far. However, this could provide a method of retaining the original structure, in cases of historical significance.

APPLICABILITY TO THE SRI LANKAN SCENARIO

A widened structure would invariably have to cater to larger dead and live loads, when compared with the existing structure. The increase in the dead load and the live load needs to be addressed in relation to the strength of superstructure, substructure and foundations of the bridge. Hence the exercise of rehabilitation could become an exercise of strengthening the existing bridge.

Most of the steel bridges in Sri Lanka, being either truss bridges or beam and slab bridges, could easily be identified with almost all the strengthening methods discussed thus far. However, methods like 'changing the load paths', may not be readily feasible, due to the narrow widths of almost all of these bridges. Further, adding or shifting the supports also may not be that feasible, since generally steel bridges being of larger spans (especially truss bridges) span fast-flowing rivers or deep gorges, making the construction cost of a pier to soar.

Most of the other methods such as increasing member cross sections, adding members etc. (except prestressing and providing continuity) have been adopted in Sri Lanka during the past to enhance the strength of steel bridges. However, it seems that these endeavours have not been documented regularly. Thus, adoption of the most common methods is probably due to the requirement of strengthening only weak members of a bridge, rather than a global strengthening.

Prestressing and providing continuity could be an ideal method for global strengthening of a steel bridge, when compared with other methods individually, due to the possibility of performing the strengthening operation while the bridge is open to traffic. However, these methods require a rigorous analysis of the modified system, subject to the induced forces due to strengthening as well as other normal traffic loads at both serviceability and ultimate limit states. **In a study by Chandrasiri & Jayasinghe (2001), the feasibility of using post tensioning was investigated for a steel bridge of 8 spans of total length of 240.0m. The bridge needed widening to provide free flow of traffic. The detailed analysis carried out indicated that it is possible to use the available trusses. The post tensioning allowed carrying the increased dead and live loads without increasing the tensile forces in members. This would allow the bridge to have an increased fatigue life although it carries additional loads.**

Irrespective of the applicability of various methods, for strengthening a particular bridge, the cost aspects of the chosen method with the improvement of the level of service provided should be the deciding criteria, in selecting a strengthening procedure. This could be achieved through estimating various costs involved in each method and by introducing what is known as an 'improvement factor' to the cost analysis (NCHRP, 293).

Improvement factor could be defined as the enhanced load effect (e.g. increase in flexural capacity of a beam at mid span) divided by the cost of the strengthening method. Hence higher the improvement factor, better the chosen strengthening method would be, thus giving us a decision making device to compare between the strengthening methods available.

DETERMINATION OF ECONOMIC FEASIBILITY

Out of the total of 3700 steel bridges in Sri Lanka 2372 bridges are with a width below 8.0 m as indicated in Figure 1. Of the 854 steel bridges 782 bridges fall on to the same category. Assuming that these steel bridges would have to be replaced or widened within the next twenty-five years, the budget requirement for superstructure replacement alone is about Rs.1.9 billion with the prices prevailing in 2001. To arrive at this cost, the data given in Table 1 was used. Based on this data, it is reasonable to consider a cost of Rs. 20000/= per m^2. The completed bridge was considered to have a width of 10.0m. The average length of these bridges is estimated as 12.0m on the basis of the data available on lengths.

In analyzing a bridge having deficiencies, the Engineer is faced with making a decision as to either replace or strengthen/rehabilitate. This decision should be based not only on the initial expenditure but also on the life cycle cost of the structure. The main problem faced in doing so is the estimation of the life of a structure, either new or strengthened. In a new structure, if designed in accordance with BS 5400, a life span of 120 years could be assumed. However, in an existing bridge, the estimation of remaining life basically depends on engineering judgement. Primarily, in steel bridges the remaining life is dictated by fatigue limits. Though there have been attempts at estimating fatigue life through field data (Mohammadi, Guralnick, et.al., 1998), these methods are based on extensive collection of data on traffic volumes, structural condition and growth rates, axle loads, etc., making them subjective too.

Hence experience in dealing with bridges is of paramount importance when estimating the remaining life of an existing or strengthened bridge. With the decision being based on economical analysis, various types of economic feasibility techniques could be utilized in arriving at a decision.

Table 1: Cost of construction of superstructure (Costing year: 2000/2001)

NAME OF THE BRIDGE	LENGTH (m)	WIDTH (m)	COST OF SUPERSTRUC TURE (Rs.)**	COST/AREA OF DECK (Rs/m²)	TYPE OF DECK
375/1 CRWB ROAD	80.52	9.8	8,438,850	10694	STEEL COMPOSITE
30/4 GDM ROAD	12.22	9.8	1,470,150	12276	PSC SLAB
2/1 DH ROAD	28	11.4	4,831,261	15136	PSC SLAB
2/1 NN ROAD	34.14	9.1	6,232,507	20061	RCC BEAM & SLAB
PARAGASTOTA BRIDGE	48.6	7.3	5,357,672	15101	PSC SLAB
KILIVEDDI ARU BRIDGE	95.25	9.8	18,311,877	19617	PSC SLAB
1/2 EOA ROAD	12.27	9.2	1,994,972	17672	PSC SLAB
MUTHUWADIY A BRIDGE	69.62	9.96	14,602,342	21059	PSC BEAM & SLAB

Source : Bridge Design Office, Road Development Authority
Abbreviations:

CRWB - Colombo Ratnapura Wellwaya Batticaloa

GDM - Galle Deniyaya Madampe
DV - Deniyaya Viharahena
NN - Narahenpita Nawala
EOA - Elpitiya Opatha Avittawa

While the AASHTO prefers the equivalent uniform annual cost method, (EUAC) (NCHRP, 293), some others have preferred Differed Expenditure method. (FHWA/RD-82/041, 1983). Sometimes, a thumb rule has also been used to determine the cost effectiveness of a strengthening scheme where it has been assumed that if the strengthening cost is less than 50% of the replacement cost, the strengthening deemed to be a feasible option. This result has been obtained probably on surveys carried out through various construction organizations, on the criteria they have used in the past on similar projects (NCHRP, 293).

For Sri Lanka apart from the thumb rule thus specified, the authors feel that a 'net present value' of the two proposals (strengthening/replacement), to be more adaptable since the method is widely used in current feasibility studies. This will basically require initial and maintenance costs prepared in a manner to indicate the cash flow pattern of the project and data on interest rates (inflation), salvage value, etc. Since these factors could be readily estimated, a rational method could be devised by calculating the net present value of the strengthening/replacement proposal based on standard economic analysis procedure, conducted for the remaining life period, by assuming that the replacement occurs at the end of such period.

CONCLUSION

The decision whether to replace or rehabilitate an existing bridge is a question faced by engineers when dealing with bridge construction. There are number of bridge strengthening methods that can be used for rehabilitation of bridges. Out of these providing continuity and addition of external prestressing are identified as the most suitable methods for Sri Lanka.

Since the replacement of the superstructure of the 689 bridges of width less than 8.0m alone would cost about Rs. 1.9 billion, it can be suggested that rehabilitation of steel bridges should be seriously pursued in future.

It is suggested that the economic feasibility of replacement and rehabilitation could be based on net present value of two alternatives. The rehabilitation would be attractive if it costs less than 50% of replacement. This indicates that there could be considerable cost savings if rehabilitation is adopted for a considerable number of steel bridges.

ACKNOWLEDGEMENT

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TYPES OF BRIDGES
Local Scenario
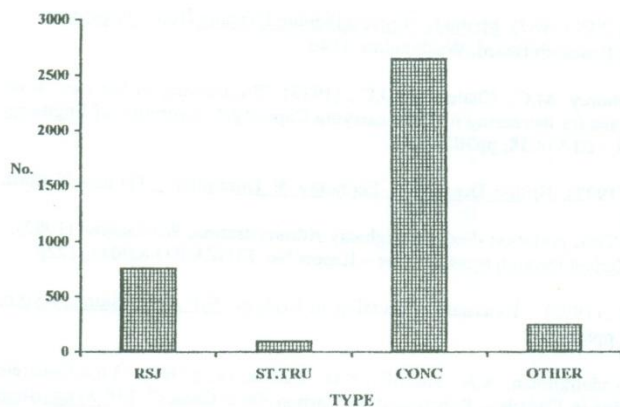
	RSJ	ST.TRU	CONC	OTHER
NO	756	98	2647	243

WIDTH OF BRIDGES
(Local Scenario)
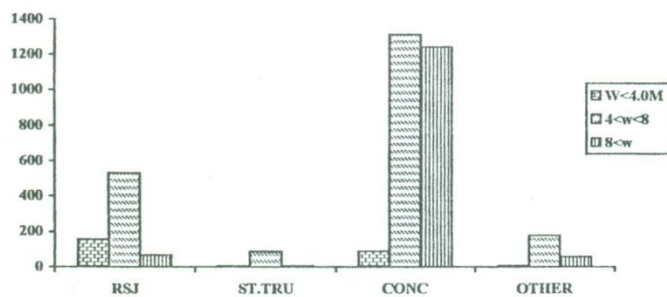
	RSJ	ST.TRU	CONC	OTHER
W<4.0m	159	6	89	7
4<w<8	530	87	1315	179
8<w	67	5	1243	57

Abbreviation

RSJ	Rolled Steel Joist System
ST.TRU	Steel through/deck truss
CONC	Concrete Bridge

Figure 1 : The Details of the Bridges Based on Type and Width

EXISTING TRUSS

MODIFIED TRUSS-1

MODIFIED TRUSS-2
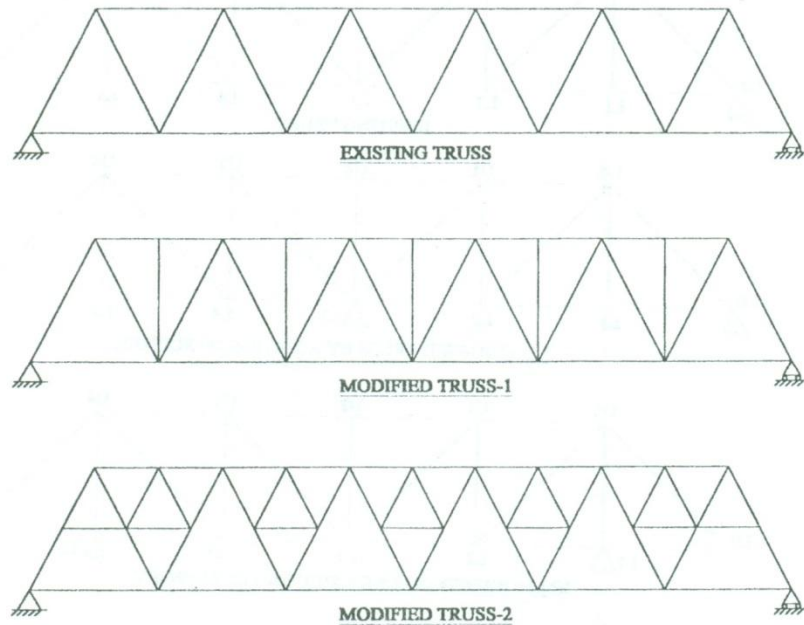
2(a).Adding supplementary members to a truss frame.

PACKING

BAILEY TRUSS

TIE RODS

TOP OF ROADWAY

FLOOR BEAM
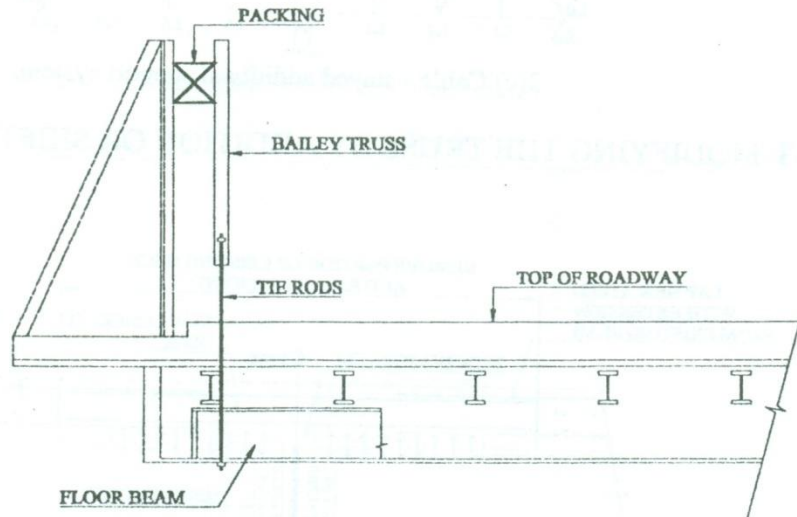
2(b).Reinforcing of a pony-truss bridge with Bailey trusses.

Figure-2 The strengthening methods for truss bridges.

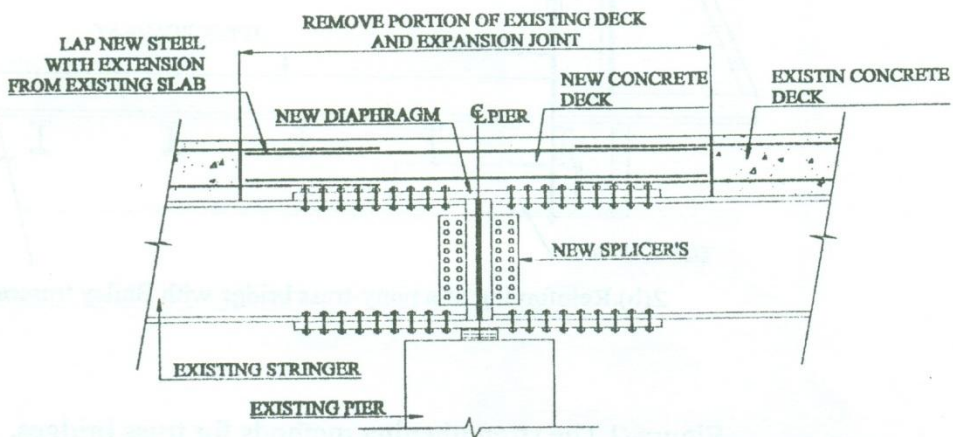EXISTING TRUSS

3(a).MODIFIED TRUSS BY ADDITION OF SUPPORT.

3(b).MODIFIED TRUSS BY SHIFTING OF SUPPORT.

3(c).Cable - stayed additional support system.
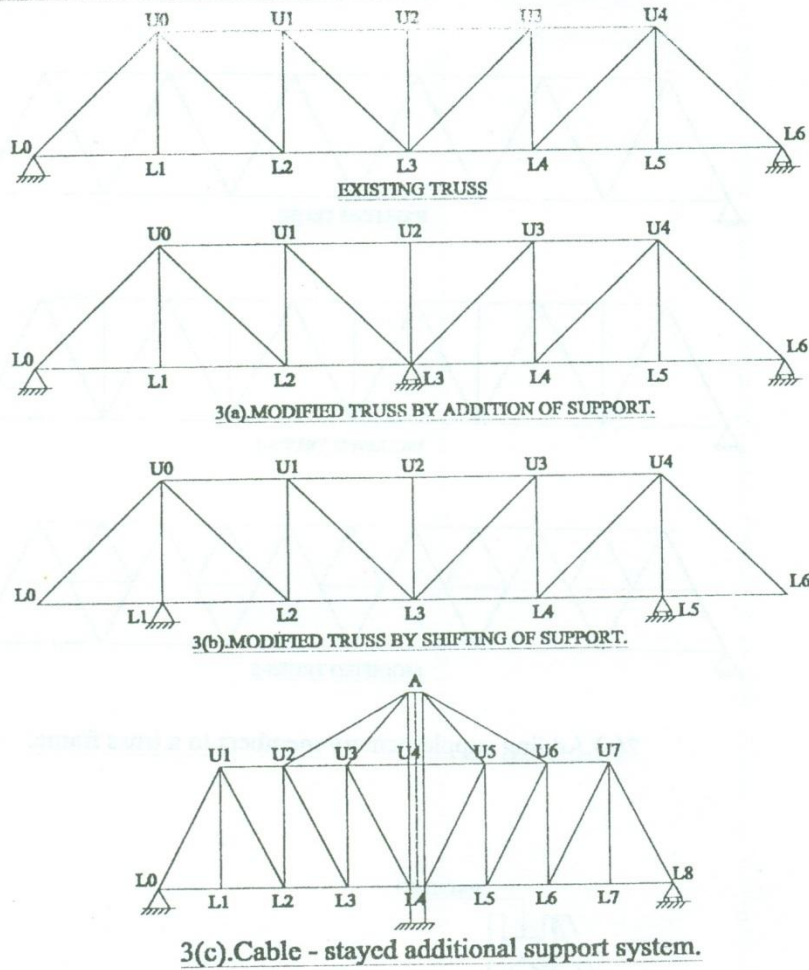
Figure-3 MODIFYING THE TRUSS BY ADDITION OR SHIFTING OF SUPPORTS.

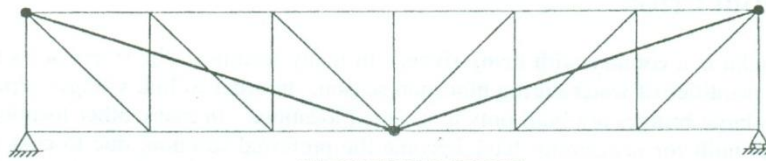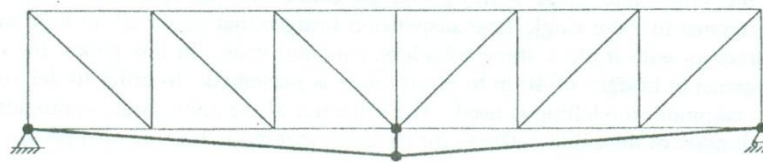Figure-4 Conceptual details of a moment-and shear- type connection.
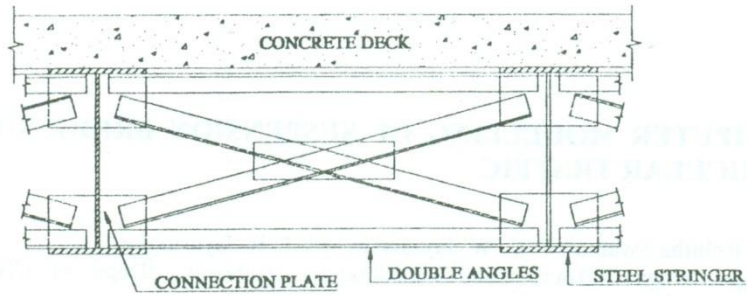
Figure-5-Typical cross frame diaphragm.
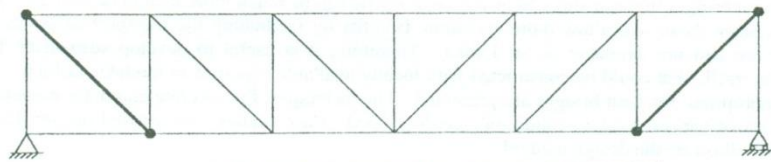
6(a).CONCENTRIC TENDON ON INDIVIDUAL MEMBERS

6(b).POLYGONAL TENDON

6(c).KING POST

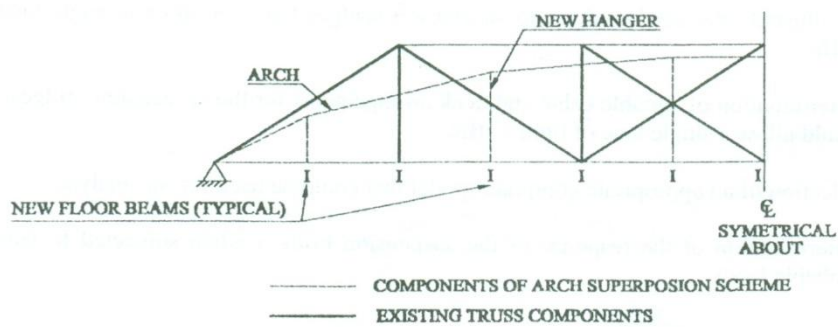Figure-6 Tendon configurations for post-tensioning trusses

Figure-7 Schematic of arch superposion scheme.