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Pre-Stressed Concrete Bridge Girder Analysis, Design & Optimization - A Review

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Abstract: ***Pre-stressed Concrete bridges nowadays have become the most widely used amongst all other bridges. Analysis and Design of such bridges are done as per various standard codes which gives satisfactory solutions to most of the design engineers. But along with that, a designer would like to optimize the structure which is obtained to make it more economical and feasible to construct. The design obtained should be safe for construction taking into consideration its cost and structural strength. Many kinds of research have been done for the optimization of bridges to obtain an economical structure. Owing to that, this review has been done regarding various methods of optimization for the girder bridges. Also, various aspects of Pre-stressed concrete bridges have been discussed to compute the overall behaviour of the structure which includes various losses, stresses, cable profile, strands, codal provisions, etc. has been discussed in details.***
Keywords: ***Pre-Stressed concrete girder, design, and analysis, optimization.***

I. INTRODUCTION

To construct any kind of bridge, it has to go through many different stages such as planning, analysis, design, and construction. Each of these stages can be explained deeply but the structural engineer mainly focuses on the stage of analysis and design of the bridge which is done after its planning. For any kind of design problem, there are many designs that are acceptable. Out of these designs, the most economical one will fulfill the engineering as well as structural standards and also an economic need. The process of finding the economic and best results with a maximum benefit that too at minimum cost is known as optimization. Due to recent advances in the structural designing field it has become very easy to get a safe design but it has become difficult to find an economical design, hence optimization technique is necessary to get the economical design, which will be advantageous in many ways such as material saving, reducing the concrete usage, etc. Hence optimization has gained a good scope in structural engineering.

Economical design, which will be advantageous in many ways such as material saving, reducing the concrete usage, etc. Hence optimization has gained a good scope in structural engineering. This study will help the other researchers to know about the various aspects of Pre-stressed concrete bridges, its analysis, and design as well as the optimization of that particular structure which will reduce its cost without affecting its strength. Various techniques of optimization have also been discussed in this study.

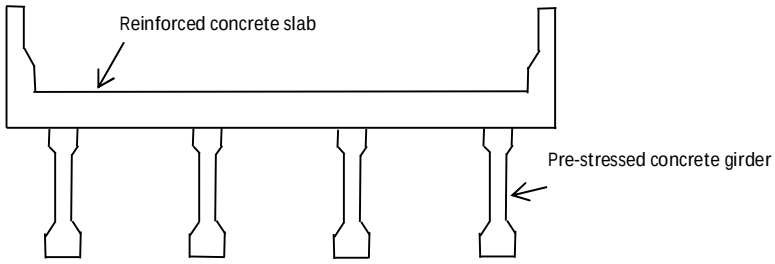


Fig. 1 Pre-stressed concrete girder bridge

A. Advantages of PSC Girder Bridge

1) Pre-stressing applies a pre-compression to that member which eliminates tensile stresses that are unwanted.
2) Deflections can be controlled by keeping it within range.
3) Spans can also be extended far beyond the limit for any ordinary reinforced concrete.
4) By pre-stressing of concrete dead load of the structure can be reduced due to which longer span members could be constructed making the structures more economical.
5) It also produces complete designs or an accurate estimate of the real cost.

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II. VARIOUS ASPECTS OF PRE-STRESSED CONCRETE BRIDGES

I-girder Bridge basically refers to a bridge in which deck slab is supported by a girder. A bridge contains three parts: the foundation; the substructure which includes abutments, pier, and pier cap; the superstructure which includes girder, bearing and deck slab. A girder bridge nowadays is the most commonly built bridge. It is basically designed, in the simplified form, as a log ranging from one side to the other side across a river or stream. Pre-stressed concrete is mainly a concrete in which internal stresses of proper magnitude and distribution are introduced so that the stresses coming from external loads are counteracted to the desired amount. In reinforced concrete members, the pre-stress is introduced by tensioning the steel reinforcement. Two methods of pre-stressing with the various losses considered in it are as follows:

1) *Pre-Tensioning:* The term pre-tensioned means that the tendons are tensioned to their full load before the placing of concrete. Losses considered during the design are elastic deformation in concrete, relaxation of stress in steel, shrinkage in concrete and creep in concrete.
2) *Post-Tensioning:* The term post-tensioned means that the tendons are tensioned after the placing and curing of concrete. Losses considered during the design are elastic deformation in concrete, relaxation of stress in steel, shrinkage in concrete, creep in concrete, friction loss and anchorage in the slip.

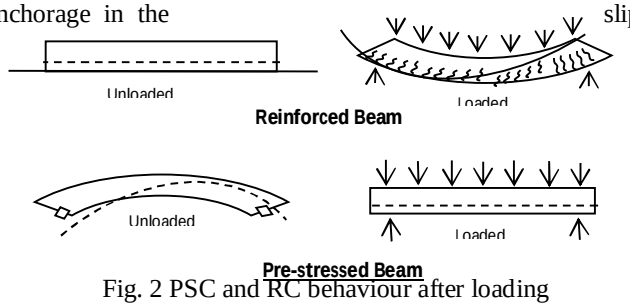


Fig. 2 PSC and RC behaviour after loading

PSC girder supporting bridges are custom for short to medium span mainly when the spans are less than 40m. Typical prestressing in multistage consists of two stages. Initially in which prestress of 1st unit (group) of tendons is acquainted to girder. Next is, when girders get erected over the piers or abutments over which deck is placed, another unit (group) of tendons is post-tensioned. For decked Pre-stressed concrete system of girder, top fibre stress of deck and bottom fibre stress of girder get verified at the time of prestressing and in service. However, Jeon had an interest in finding the span ranges for the Prestressed concrete girder bridge. The feasible most span along with the corresponding no. of tendons may readily be decoded from the viable design domain without the trial and error traditional design technique. A quantitative evaluation for the increase in span length is performed by choosing a sample bridge to exhibit a number of benefits by the proposed scheme. The consequences suggest that increasing the strength of girder, decked PSC girder & PSC girders made continuous earlier than a deck placement, and multi-stage pre stressing with the secondary tendons pre-stressed earlier than of girder and deck's composite action are very effective, therefore would be essential components for enhancing the span length [1]. Kumar carried out design of box girder in which numerous span/depth ratios had been taken for analysis. Deflection and stresses were already within the permissible limits for all the instances. As the depth of box girder decreases, the pre-stressing force get reduced and no. of cables will be decreased accordingly. Due to pre-stressing, utilization of concrete strength achieved was additional and it additionally governs the serviceableness very well. In line with IRC:112, it needs accrued cover for pre-tensioned strands in addition to post-tensioned ducts, which can ultimately result in accrued thickness of webs and deck slab for PSC bridges. If cross-section and moment applied are same, then the steel difference seems to be quite noticeable as compared to WSM [2]. An instance is presented to demonstrate the sensible application of the strategy that was primarily based on a real-life project named "Teesta Bridge" which was to be constructed in northern Bangladesh. The cost statistics for labours, materials, fabrication, and installation which are used to get the most suitable design are kept the same as it was once taken for the existing design. The price most effective design was received in which it was observed that the optimal I-girder bridge system configuration yielded the least overall cost which was discovered to be 35% more low-priced than that of the current design. In the most efficient design, girder spacing is higher because of which the number of girders in the bridge which had been received in the most fulfilling design discovered to be much less than that of the current design. In the optimum design of bridge, the depth of girder, width of top flange, thickness of bottom flange and thickness of slab are observed to be comparatively larger whereas the thickness of the top flange, width of backside flange, width of web, prestressing steel and reinforcement of deck slab received have been lesser than the existing design [3]. Antonio investigated the complex behaviour of a two-span continuous box girder bridge when it is in the construction process as well as under permanent loadings. A model was prepared and constructed according to the

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design and then tested for the results. Time-dependent concrete properties with support reactions, deflections, and strains in concrete and steel were measured for five hundred days. Vital time-dependent stresses and internal forces redistributions throughout the entire bridge were conjointly measured. The results which had been acquired from the study were compared to a numerical model formulated for non-linear and time-dependent analysis of segmentally erected reinforced as well as PSC structures [4]. Beam line analysis has been done for the cost and performance optimization of pre-stressed concrete bridge girder. A simply supported model is prepared to test the variables in the section and the excel sheet is prepared for analysis and design of bridge which will calculate load forces, moments and shear. It will also calculate the design of the girder considering the proportion of pre-stress cables with the eccentricity as well as a required force of pre-stressing. It also performs the estimation of the concrete quantity. The spreadsheet is validated by preparing various numbers of models using finite element method having different geometry which were again analyzed by SAP-2000 [5].

III. OPTIMIZATION OF STRUCTURE

Optimization generally referred to as getting an economical and best solution for the problem for a given set of parameters. It ultimately reduced the cost of the structure and provides a good solution as structural point of view. Researches show that high-strength concrete is essential in prestressed concrete, because the material provides high resistance in tension, shear and bond. In the zone of anchorages, since the bearing stresses are higher, high-strength concrete is especially most popular to attenuate cost of structure. Once there's a use of high-strength concrete, it reduce the cross-sectional dimensions of structural parts of prestress. Once dead-weight of the fabric is reduced, longer spans end up to be technically and economically possible. The Rande Bridge which is in Vigo (Spain) has been chosen as the optimization problem. The objective was to optimize the weight of cables in cable-stayed bridges. The bridge considered for the research is a cable-stayed bridge having a single-span. For the optimization process, design variables contemplated are the areas of cross section, no. of cables and cable forces under post-tensioning process as well as the anchor positions on deck. Optimization is carried out with two different strategies using genetic algorithm as well as gradient-based algorithms. The main aim was to identify a strategy for reducing the steel volume in the system of cable [6]. A review on cost optimum design of concrete structures is done which was published in archival journals. Various concrete structure included in the study are beams, columns, slabs, frame structures, folded plates, bridges, water tanks, tensile members, shear walls and pipes. Many important and interesting results are summarized from the review [7]. Cost optimization for T-beam RCC girder has been carried out. The fundamental goal of the research was to limit the expense of the of bridge system for getting the affordable structure by thinking about the expense of materials. The design variables considered for girder are girder depth, width of web and depth of deck slab. Design constraints are considered as per IRC: 21. Optimization was done for various grades of steel and concrete. After preparing the model, structure is analysed by direct methodology of design. Problem which is developed for optimization is in non-linear computer programming by Sequential Unconstrained Minimization Technique. For the purpose of optimization, a model is analysed which is designed with the help of Matlab software. After obtaining the results, it is compared to the conventional procedure of design [8]. Cost optimization of bridge superstructure is carried out in which the objective is to minimize the cost required for bridge system considering the material cost as well. Optimization is mainly carried out with different grades of steel and grades of concrete. The results obtained for the optimum design of girder which then compared and conclusions were drawn. For the whole process computer code was developed in MATLAB. After validation of the code, the results were calculated with the analytical results and proposed to obtain safe as well as economical design for the bridge superstructure [9]. Jinsong bestowed an optimization technique for maintenance strategy for concrete girder bridges seeable of the factors in the main for life cycle and service life maintenance cost and performance indicators. The reliability and condition indices are taken as performance indicators. The performance indicators deteriorated processes with maintenance actions still as while not maintenance actions are delineated as multi-linear models. Designing optimization for the life cycle maintenance of deteriorating bridges is then developed as a multi-objective downside to being resolved by genetic rule with controlled superiority. The responsibility index, condition index, life cycle maintenance service life value are the four objective functions that are thought-about one by one [10]. Cohn has done the optimization in three levels for the superstructure of short and medium span bridge for highway. It consists of structural configuration optimization, component optimization and overall system optimization. The objectives considered for optimization are concrete consumption, cost, prestressing steel as well as superstructure depth. Objectives considered can be one, two or more from these mentioned here. The solution for optimization can be found out by nonlinear programming as well as sieve-search techniques. The study will lead to some important results such as systematic procedure for design of bridge, direct design method to obtain an optimized system of bridge, a particular logical approach for standard precast sections optimization and simple criteria for optimization for preliminary design [11].

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IV. METHODS USED FOR OPTIMIZATION

Optimization of flexural members made of reinforced concrete by natural velocity field method has been carried out. Shape optimization basically includes modification of the shape of a member which is initially a rectangular section. Also, the depth and breadth along with length variations are taken into consideration. Using sequential quadratic programming technique, shape changes which are necessary have been computed. To optimize the number of reinforcement bars (main bars only) and diameter, a genetic algorithm has been considered. For the design of reinforced concrete section, limit state approach has been adopted. Optimization problem formulation, finite element model prepared and solution procedure has been described. The problems for design are cantilever beam, simply supported beam and two span continuous beams with uniformly distributed loads. The results obtained show considerable savings in cost and material of about 40–56%. The proposed procedure will also lead to significant cost saving, mainly if the mass-produced precast members are considered as well as for heavy cast in situ members such as girders of the bridge [12]. Cost optimization of a particular bridge system is presented.

Bridge considered is precast, pre-stressed I-beam concrete bridge . Cost optimization is done by for the costs of reinforcement steel, concrete as well as formwork. The problem is developed which was a mixed integer-discrete problem. It is solved using the robust neural dynamics model given by Adeli and Park. An illustrative example is also presented to show a demonstration of the practical application of the methodology used for bridge design [13].

To obtain the optimal design for structural concrete beams, a computer approach is presented. This method allows considering the various limit state constraints as specified in the standard code for solving the optimization problem. Optimization was mainly done to minimize the amount of reinforcement, to find out the effect of steel cost ratios, to optimize the shape of a section for PSC beams, to analyze the given design respect to the specified criteria [14]. Lounis presented a practical and proficient approach for the optimization problem of prestressed concrete structures. This research mainly carried out for two or more objectives which are possibly contradictory and at the same time must be satisfied. The optimization problem which consists of a single objective is solved by the Lagrangian algorithm.

Two numerical examples exemplify the application of the proposed approach to the design of a system of a pretensioned highway bridge and a slab of a posttensioned floor that too for the two conflicting objectives which are minimum initial camber and minimum cost. A compromise between the proposed two conflicting objectives was achieved by the Pareto optima. It represents more rational and realistic solutions than the solutions which were obtained by independently optimizing each of the objectives function [15]. Sami provided the design engineers with a direct and uncomplicated method to optimize a pre-stressed pre-tensioned I-girder to obtain an economic design. The bridge considered for the study has a single span which is cast-in-situ with a reinforced concrete deck. This deck acts compositely when the girder is placed over it under dead load, superimposed load and vehicular live load. A program is developed based on linear programming for constructing two charts. The first chart is for obtaining more economical girder and its spacing while the second chart for obtaining pre-stressing force. To evaluate the effects on values of a maximum span of the girder and by changing the design variables, linear programming is formulated required pre-stressing force [16].

V. CONCLUSIONS

A. There is also a great need of carrying out some researches on cost optimization of real 3-dimensional structures, especially for large structures in which optimization can result in significant savings.

B. According to IRC provisions, WSM consumes more steel as compared to LSM, so it would be advisable to change the steel grade instead of increasing the concrete grade for greater percentage of steel variational difference.

C. The practical spacing between I-girders should always be maximum in order to obtain the most economical structure. Also, it is specified that if there is no restriction for the depth of the superstructure then it will be beneficial to use the minimal number of girders which are deep.

D. The actual cost saving percentage which can be obtained for optimum design for superstructures of bridge primarily depends on a span of slab and material grade with which care should be taken the key parameter which will affect the girder spacing is the cost of the bridge and its performance. This variable is normally conjugated with a number of girders and the total width of the bridge.

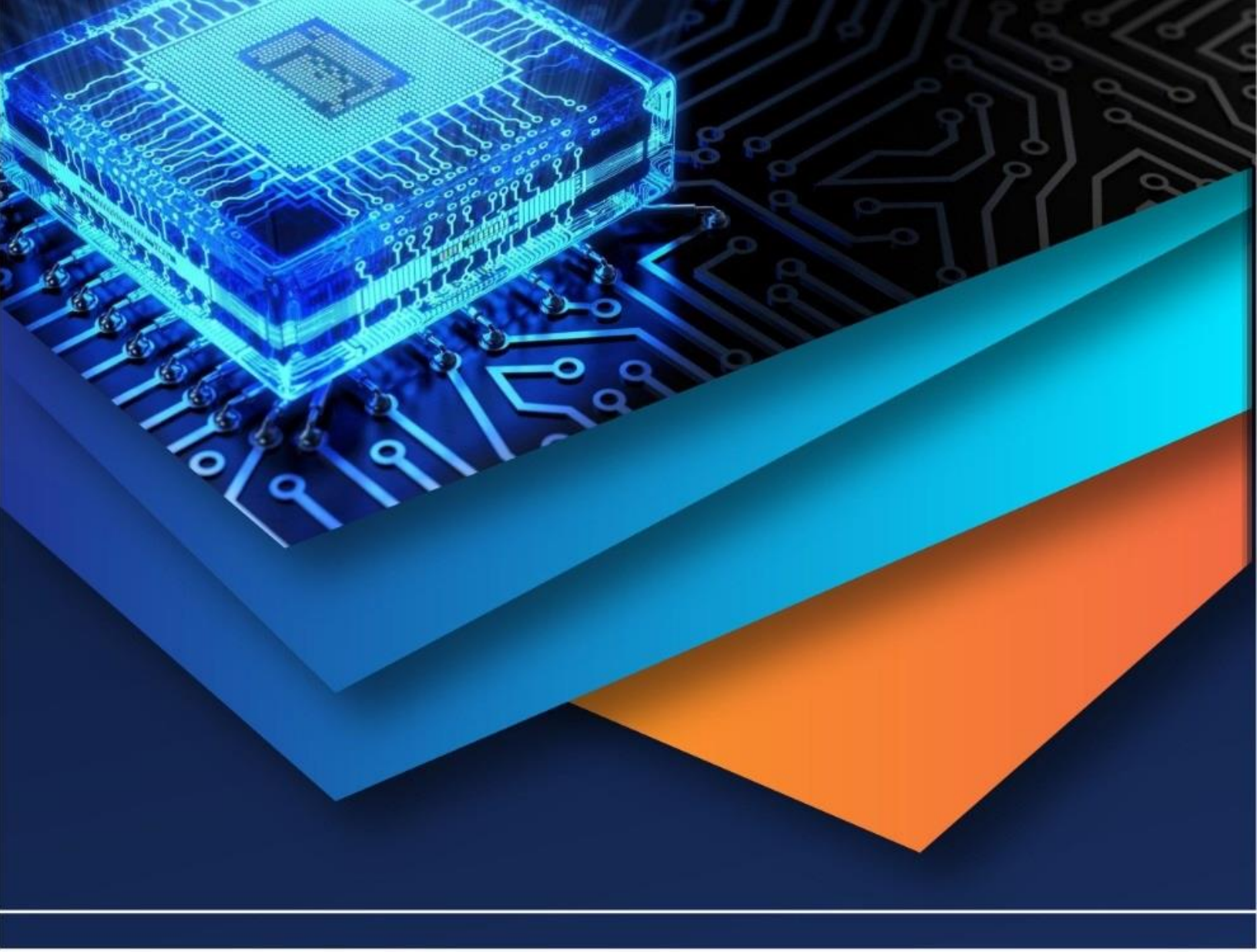
E. The optimum value invariably depends on the width of the overhang. If the width of the overhang is more than half the girder spacing, then dead and live load demand on the exterior girders will significantly increase as compared to the demand on the interior girders.

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