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Economics of Continuous R.C.C. Beams Vis-à-vis Continuous Pre-stressed Concrete Beams

A.R.Mundhada, Mohammad Shahezad

Abstract—This paper presents the economics of continuous R.C.C. beams vis-à-vis continuous pre-stressed concrete beams. This work includes the design and estimates of continuous R.C.C. beams and continuous pre-stressed concrete beams of various spans. In today's jet age, we have a host of construction techniques at our disposal. Steel structures, R.C.C. Structures, Core and hull type of structure (combination of steel & R.C.C. construction), Ferro-cement and prestressed concrete are some examples. At times this choice available leads to confusion. The best way is to select the type of construction, depending on the circumstances and type of structure. The aim of this paper is to design medium span continuous R.C.C. beams as well as continuous pre-stressed concrete variety and then compare the results. Programming in MS EXCEL is done to design the beams. The idea is to reach a definite conclusion regarding the superiority of the two techniques over one another. Results reveal that a continuous R.C.C. beam is cheaper than continuous pre-stressed concrete beam for smaller spans but vice versa is true for larger spans.

Index Terms— Beams, Continuous, Economics, Limit State Method, Post-tensioned, Prestressing, R.C.C.

1 INTRODUCTION

1.1 Importance & Necessity

Without any semblance of doubt, Reinforced cement concrete construction has been the most revolutionary construction technique of modern times. Combining the high compressive strength of concrete with high tensile strength and elasticity of steel has resulted in a composite material that is strong, durable and economical. Moreover, it is time tested.

One of the greatest assets of "homo-sapiens" is their quest for excellence. The human being has constantly refused to sit over his laurels and become complacent. This has often resulted in new invention and improved products and techniques. Very week tensile strength of concrete lead to discovery of R.C.C. Bulkiness of R.C.C resulted in the invention of shells. The problem of serviceability associated with the R.C.C. structures sent the human mind working over-time. The solution was found in prestressing. Like ordinary reinforced concrete, prestressed concrete consists of concrete resisting compression and reinforcement carrying tension. Prestressing became essential in many applications in order to fully utilize the compressive strength of reinforced concrete and to eliminate or control cracking and deflection.

Prestressed concrete is the most recent major form of construction introduced in the structural engineering. It has become a well established method of construction as the technology is now available in all developed and in many developing countries. Today, prestressing is used in buildings, underground structures, communication towers, floating storage and offshore structures, power stations, nuclear reactor vessels, and numerous types of bridge systems.

The aim of this work is to design medium span beams of R.C.C as well as prestress concrete variety and then compare the results. The idea is to reach a definite conclusion regarding the Superiority of the two techniques over each other.

1.2 Scope

This work includes the design and estimate of beams of various spans, ranging from 8.0 M to 30.0 M, by R.C.C. and prestressed concrete techniques. For smaller spans, associated with normal building works, prestress concrete construction becomes too cumbersome, irrespective of the economics involved. For very large spans, the depth required for an R.C.C. beam becomes impractical. Intensity of assumed loading is kept large enough, so that the factored bending moment will be comparable to that developing in case of small buildings. Post-tensioning is preferred as it is in vogue, in construction of large span beams.

- A.R.Mundhada
  Professor, Department of Civil Engineering, P.R.M.I.T. & R, Badnera, Amravati, Maharashtra, India-444701,
  E-mail:ashok_mundhada@yahoo.com
- Mohammad Shahezad
  PG Student, Department of Civil Engineering, P.R.M.I.T. & R, Badnera, Amravati, Maharashtra, India-444701,
  E-mail:mohd.shahezad@gmail.com

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2 CURRENT STATUS

Although several research studies have been conducted on the economics of R.C.C. beams vis-à-vis prestressed concrete beams, there is little reported work on the same. An exhaustive literature review revealed that a minimum amount of research work had been done in India.

M.Z.Cohn [1] The objectives of the paper are to present a practical design approach to nonlinear design for prestressed concrete structures and to identify its potential benefits. The paper also demonstrates the conflict between desirable plastic redistribution (at ultimate limit state) and zero or limited cracking (at serviceability limit state) for fully prestressed concrete structures. Optimization results suggest that partially prestressed concrete structures represent the most economical compromise between these conflicting criteria, and the optimal prestressing degree strikes a good balance between adequate service conditions (stresses, cracking, and deflection) and economy. Optimization of prestressed concrete beams is cast as a nonlinear programming problem and is solved by the projected Lagrangian algorithm. Examples of (three-span and two-span) continuous-beam optimizations illustrate the method and its features, as well as resulting differences between full and partial prestressing design solutions.

Anthony J.Wolanski [2] this thesis is a study of reinforced and prestressed concrete beams using finite element analysis to understand their load-deflection response. A reinforced concrete beam model is studied and compared to experimental data. The parameters for the reinforced concrete model were then used to model a prestressed concrete beam. Characteristic points on the load deformation response curve predicted using finite element analysis were compared to theoretical (hand-calculated) results. Conclusions were then made as to the accuracy of using finite element modeling for analysis of concrete. The results compared well to experimental and hand calculated.

K.H.Yang [3] This paper evaluates the strut-and-tie model specified by ACI 318 05 and mechanism analysis of the plasticity theory in predicting the load capacity of 75 reinforced concrete continuous deep beams tested in the literature. The influence of such main parameters as compressive strength of concrete, shear span to-overall depth ratio, main longitudinal bottom reinforcement, and shear reinforcement on the load capacity is also investigated using both methods and experimental results. Experimental results were closer to the predictions obtained from the mechanism analysis than the strut-and-tie model. The strut-and-tie model highly overestimated the load capacity of continuous deep beams without shear reinforcement.

Young Yang [4] The influence of the moment distribution on the shear capacity of continuous beams has been investigated in this paper. To that end a series of experiments on cantilevered simply supported beams were carried out at Delft University of Technology. Two point loads were applied; one at the cantilever end and one along the span with a certain shear span *a*. By controlling these loads the ratio between the hogging moment at the support (*M*-) and the sagging moment in the span (*M*+) was kept constant. The main variables in this study are *M*-/*M*+ and *a*/*d*. In this paper the experiments and the phenomena observed are described and recommendations are given to the design practice.

Based on the test results,

• For continuous beams, the moment distribution prevents the development of diagonal cracks in the vicinity of the point of inflection.

• One may replace the value of *a*/2*d* with *M*/2*Vd* in the load reduction factor β in Euro code in the cases of continuous beams.

Y. Frostig [5] The role of secondary moments and amount of stress redistribution at various stages of loading up to the collapse of continuous prestressed concrete beams is investigated. The related questions arising from contradictory experimental evidence and standard recommendations are examined within the context of the usual engineering assumptions accepted by the American and European Codes of practice. Both direct and incremental techniques are used for the analysis of the hyperstatic response at specified levels beyond the elastic limit, and throughout the entire loading history. A continuous beam with three unequal spans and three potential plastic hinges is used to develop the theoretical concepts and to illustrate their practical application.

3 METHODOLOGY

To begin with, an R.C.C. beams was manually designed by using the limit state method based on IS: 456-2000. Based on the steps & formulas involved, a design program was prepared in MS EXCEL. The veracity of the program was checked by first designing the manually designed beams by using the program & comparing the results. Since in field, a mix richer than M: 30 is seldom used for RCC, the grade of concrete was maintained at M: 30 for R.C.C.

An identical procedure was followed for prestress concrete beams. The manual design was based on the limit state method suggested by the IS: 1343-1980. The program for designing the same was developed by using MS EXCEL & its fidelity was checked by first solving the manual problem & comparing the results. Since the onus was on prestressing, the beams were designed for various concrete

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grades between M: 30 to M: 50. Figure 7 & Figure 8 in IS: 1343 were incorporated into the program as a link so as to directly calculate the permissible compressive stresses. Design was carried out for parabolic cable profile only, which is the most popular one. Only Rectangular-sections were considered.

Programs were also prepared for estimating & costing. Rates are based on the latest CSR in Maharashtra. In case of prestress concrete, some of the rates were obtained from a well-known private Infrastructure company.

Prestressed concrete beams of all concrete grades were designed for TYPE 3 only which is the practice in field. TYPE 1 & TYPE 2 structures are used only in special cases like Water Tanks, Pipes, Sleepers & Electric Poles.

4 RESULTS & DISCUSSION

Table 1 below gives the cost/beam in rupees for various spans for both R.C.C. beam in M: 30 grade concrete & prestress concrete beam in M: 30 & higher grade concretes.

Figure 1 below depicts the same statistics with the help of bar charts.

Figure 2 below is a short form of Figure 1 where R.C.C. beams are compared with prestress concrete beams of only two different grades of concrete.

The cost/prestress concrete beam includes the cost of accessories like split cones, bearing plates, sheathing tubes, grouting etc.

In our country, concrete grade higher than M: 30 is generally not used in case of RCC construction. Furthermore, simply supported T beams mostly result in under-reinforced sections. Savings resulting from using a higher grade of concrete are meager in case of under-reinforced concrete & high in case of a balanced or doubly reinforced section.

The statistics makes interesting reading. For spans up to 10m, R.C.C. beam cost only half of their prestress concrete counterparts. But above 10m prestress concrete starts catching up. The breakeven point comes at around 18m. This is interesting as in field too halls/auditorium without any intermediate column is hard to find beyond 55-60 feet (@ 18m) span.

For spans between 20-25m, R.C.C. beams become costlier by 25-30%. This may not sound much especially if we consider the hassles associated with prestressing like skilled workmanship & need for superior quality control. But we must not forget that along with these minor inconveniences prestressing delivers a structure that is better from limit state of serviceability & durability point of view. But the clinching argument in favour of prestressing, at or after 20m span is the sheer size of an R.C.C. beam beyond this point. Any reduction in depth, assuming that the actual deflection will not violate limit state of serviceability, will almost certainly require a width that may not be possible architecturally. The sheer bulk of an R.C.C. beam will pose problems during construction & may warrant increased floor height that will not only add to the cost but will also culminate into an inconvenient & tiresome staircase.

At @ 30m span, the depth of an R.C.C. beam becomes so impractical that it pushes economics in background. That is why spans of this magnitude without an intermediate support are hard to locate in R.C.C. structures. Legend has it that when the100′× 100′ hall of the famous "Haj House" in Mumbai was constructed in R.C.C. some 25 years back, the bar-binders used to walk through the reinforcement cage of R.C.C. girders standing upright!

Prestress concrete beams were simultaneously designed in different grades for identical spans. The results clearly show savings in cost with higher grades of concrete. This is in consonance with the current field trend of designing richer mixes in order to achieve economy in case of R.C.C. construction.

TABLE. 1: "Economics of Continuous R.C.C. Beams vis-à-vis Continuous Post-tensioned Prestress Concrete Beams"

Economics of Continuous R.C.C. Beams vis-à-vis Continuous Post-tensioned prestress concrete Beams				
SCHEDULED FOR CONTINUOUS RCC BEAMS & CONTINUOUS POST-TENSIONED PRESTRESS CONCRETE BEAMS ESTIMATE DETAILS				
Span (m)	**Grade of concrete**	**Estimated Cost of Prestress Concrete Beams**	**% Of Cost**	**Estimated Cost Of RCC Beams**
8	M_{30}	52274.00	-41.01	37070.00
	M_{40}	48980.00	-32.12	
	M_{50}	46136.00	-24.45	
12	M_{30}	95594.00	-24.22	76958.00
	M_{40}	91196.00	-18.50	
	M_{50}	98725.00	-28.28	
15	M_{30}	154072.00	-3.94	148228.00
	M_{40}	138931.00	+6.27	
	M_{50}	144058.00	+2.81	
18	M_{30}	218907.00	-0.66	217464.00
	M_{40}	212378.00	+2.33	
	M_{50}	212041.00	+2.50	
20	M_{30}	270434.00	+16.55	324092.00
	M_{40}	262540.00	+18.99	
	M_{50}	253369.00	+21.82	
22	M_{30}	327721.00	+15.70	388778.00
	M_{40}	317202.00	+18.41	
	M_{50}	310565.00	+20.11	
25	M_{30}	433889.00	+14.23	505897.00
	M_{40}	412346.00	+18.50	
	M_{50}	403275.00	+20.28	

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30	M_{30} M_{40} M_{50}	588423.00 575595.00 562896.00	--	An R.C.C beam of 30m span will require an impractical depth.

Figure 1.0: Variation of Cost with span of the Beam

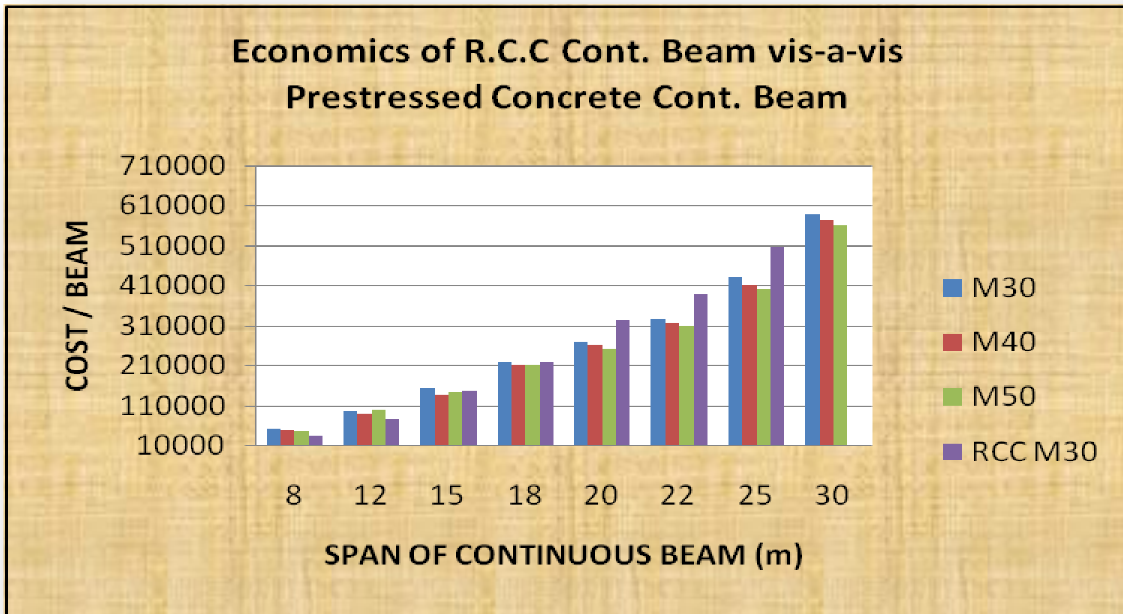
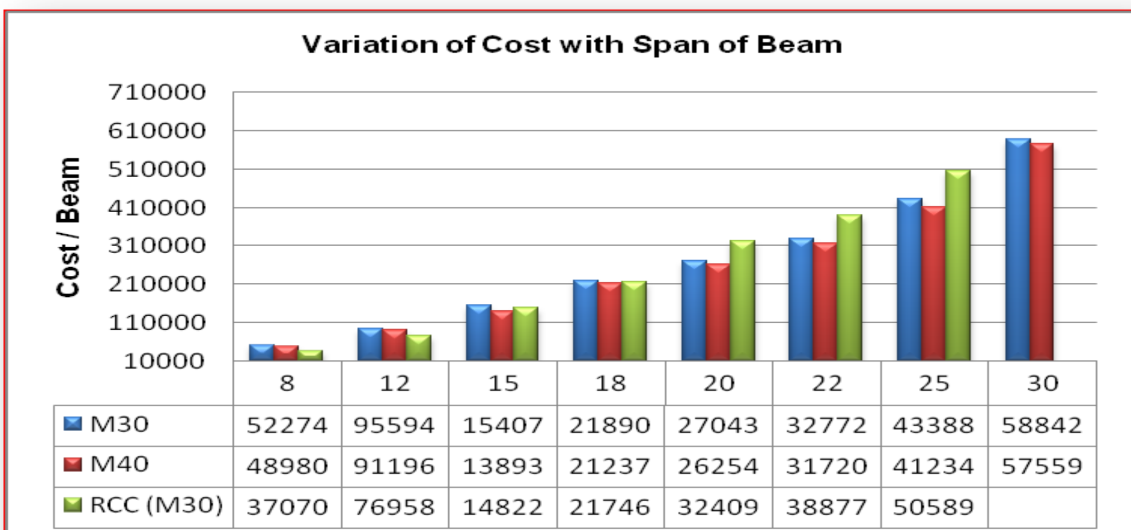


Figure 2.0: Variation of Cost with span of the Beam



Span of Beam (m)

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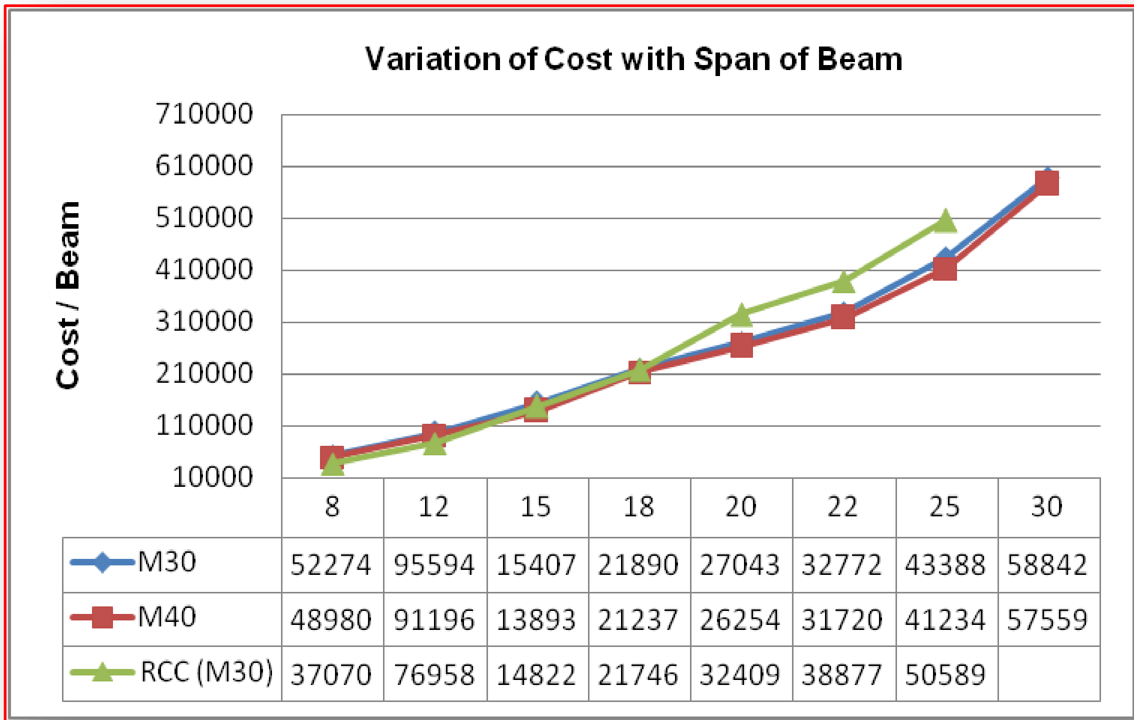
Figure 3.0: Variation of Cost with span of the Beam



Span of Beam (m)

5 CONCLUSIONS

A couple of decades back, when prestressing was not in vogue in India, R.C.C. beams used to be cheaper even for 25m spans. This is because the mix design for high strength concrete used to be based on 500kg/m^3 (i.e. 10 bags of cement/m^3) as permitted by IS: 456-1978. With modern methods of mix design based on maximum 8 bags of cement/m^3 (to minimize shrinkage & creep) the cost of high grade concrete has come down. Furthermore, the price difference between HYSD bars & high tensile steel used for prestressing has come down to 25-30% from more than 100%. Ditto for fixtures & accessories associated with prestressing. These used to be very costly then but have now become affordable because of the greater demand resulting in economics of scale for the manufacturers.

In a nut shell, for spans up to 10-15m, R.C.C. beams are preferable. For spans between 15 to 20m, the decision should be based on other factors like the size & location of the project. For spans beyond 20m, prestress concrete beams are decidedly superior as compared to conventional R.C.C. beams. In fact for spans beyond 25m, conventional R.C.C. beams become impractical & cease to remain an option.

6 FUTURE SCOPES

Economics of R.C.C. arches & R.C.C. Vierendeel girders can be studied vis-à-vis prestress concrete for spans beyond 25m.

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