Economics of Continuous RCC and Prestressed Concrete Beam and Design in Ms-Excel

Sucharita De
M.E. Scholar at Bhilai Institute of Technology, Durg Chhattisgarh India

Shraddha Sharma
Associate Professor at Bhilai Institute of Technology, Durg Chhattisgarh India

Abstract - The thesis considers the analysis of two-span Continuous RCC and Pre-stressed (pre-tensioned & post-tensioned) beam of 6.0m each having cross-section of 200x300mm with M-40 grade of concrete manually in Ms-Excel and in software i.e. in STAAD. Pro. RCC Continuous beam has been analysed based on IS 456:2000 and Pre-stressed Concrete Beam has been analysed based on Three –Moment theorem and codal provisions of IS 1343:2012. Economics of both the types of beam have been studied and found that the conventional method i.e. RCC construction is cheaper than the newly evolved Pre-stressed Construction because the later requires great instruments like weights, pulley blocks, screw jacks, pressure gauges along with High tensile steel (alloy of carbon, manganese, sulphur, phosphorus & silicon) and skilled manpower to operate these to impart the prestressing force.

Keywords: Continuous Prestressed Beam, Primary Moments, Redundant Reactions, Secondary Moments and Three Moment Theorem.

I. INTRODUCTION

Reinforced cement concrete is a complex material, in which concrete's relative low tensile strength and ductility is counteracted by the inclusion of reinforcement having higher tensile strength and ductility. This reinforcement is usually embedded passively in concrete before the concrete sets. This reinforcement scheme is generally designed to resist tensile stresses in particular regions of the concrete that might cause unacceptable cracking or /and structural failure. On the other hand prestressed concrete is a method for overcoming concrete's natural weakness in tension. The name prestressed concrete makes use of predetermined force or moment to a structural member in a manner that the combined internal stresses in the member resulting from this force or moment and from anticipated conditions of external loading will be confined within specific limits. This sets up initial compressive stresses in member with a view to eliminate or materially reduce the tensile stresses. The new methods used for better result and economic design are introduced namely Pre-tensioning and Post tensioning. There are various ways of reinforcing the structure at various stages of concrete hardening. Before setting and hardening it is known as Prestressing and after it is post tensioning. In other words Prestress is defined as a method of applying pre-compression to control the stresses resulting due to external loads below the neutral axis of the beam tension developed due to external load which is more than the permissible limits of the plain concrete. The pre-compression applied (may be axial or eccentric) will induce the compressive stress below the neutral axis or as a whole of the beam c/s. Resulting either no tension or compression. Depending on the feature of the design construction, methods of applying prestress and purpose of structure, prestressed concrete construction may be classified into a number of groups and one of the is pre-tensioning and post-tensioning.

Pre-tensioning is the method of prestressing in which the tendons are prestressed before the concrete is placed and the tendons passing through the mould are temporarily anchored against some abutments. This tension is maintained when concrete is placed and when it is sufficiently hard, the end of the tendons are slowly released, thereby transferring the pressure from steel to concrete as compression by static friction.

Post- tensioning is the method of prestressing where the concrete is poured around a duct and tendons are fished through the duct and tensioned by hydraulic jacks, after the concrete has set. When these tendons are sufficiently stressed, they are wedged in position and a tension is maintained after jacks are removed, transferring pressure to concrete. The duct is then grouted to protect tendons from corrosion.

Advantages of Prestressed Concrete are as follows:

1. The use of high strength concrete and steel in prestressed members results in lighter and slender members than is possible with RC members.
2. In fully prestressed members the member is free from tensile stresses under working loads, thus whole of the section is effective.
3. In prestressed members, dead loads may be counter-balanced by eccentric prestressing.
4. Prestressed concrete member posses better resistance to shear forces due to effect of compressive stresses presence or eccentric cable profile.
5. Use of high strength concrete and freedom from cracks, contribute to improve durability under aggressive environmental conditions.
6. Long span structures are possible so that saving in weight is significant and thus it will be economic.
7. Factory products are possible.
8. Prestressed members are tested before use.
9. Prestressed concrete structure deflects appreciably before ultimate failure, thus giving ample warning before collapse.
10. Fatigue strength is better due to small variations in prestressing steel, recommended to dynamically loaded structures.
11. Prestressed beams never fail under direct shear or punching shear failure.
12. Prestressed concrete can be used with advantage in all those structures where tension develops, such as tie and suspender of a bow string girder, railway sleepers, electric poles, upstream face of gravity dam, etc.

Disadvantages of Prestressed Concrete are as follows.

1. The availability of experienced builders is scanty.
2. Initial equipment cost is very high.
3. Availability of experienced engineers is scanty.
4. Prestressed sections are brittle.
5. Prestressed concrete sections are less fire resistant.
6. It requires high tensile steel, which is 2.5-3.5 times costlier than mild steel.
7. It requires high quality dense concrete of high strength. Perfect quality control in production, placement and compaction is required.

II. OBJECTIVE OF STUDY

In this project the study has been done to gain knowledge about the methods designing of beam by conventional RCC methods and Prestressing method, also its comparison by using Staad.pro software tool.

Depending on the feature of the design construction, methods of applying prestress and purpose of structure, prestressed concrete construction may be classified into pre-tensioning and post-tensioning. Thus for this a continuous beam of simply supported nature having span of 12 meter and more; is designed for both the methods along with the conventional method. Evaluation of results will be done along with design in MS-Excel.It is here by also tried to concentrate the study for economics of design to facilitate cheaper but better quality structure within prescribed specifications of codes as per Indian standards design codes of practice IS: 1343 – 2012 and IS: 456 – 2000.

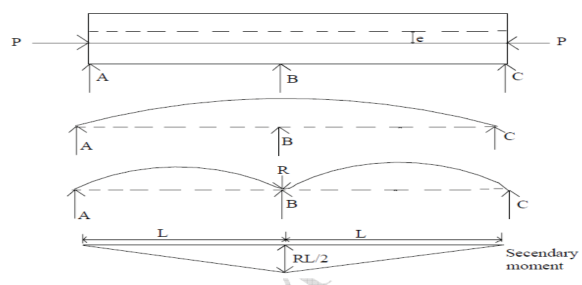
III. SCOPE OF STUDY

Without much doubts RCC constructing has been the most revolutionary construction technique of modern times but on the other hand prestressing has become essential in many applications in order to fully utilize the compressive strength of RCC and to eliminate or control cracking and deflection. This project thesis will be helpful of design of beams, underground structure, communication towers, floating storage and off shore Structures, power stations, nuclear reactor vessels and numerous types of bridges using prestressing techniques that requires clear spans ranging from 15 m and above. A span of such range in RCC considers a depth that is impractical and uneconomical.

IV. METHODOLOGY

When an indeterminate beam is prestressed, redundant reactions will develop due to redundancies exercising a restraint at the supports. While a statically determinate structure is free to deform when prestressed, a continuous structure cannot deform freely. However, the deflections should conform to the law of consistent deformation. The redundant reactions, which develop as a consequence of prestressing and indeterminate structure result in secondary moments. The formation of redundant reactions and secondary moments are examined with reference two span continuous beams, prestressed by a straight cable at a uniform eccentricity throughout the span as shown in fig 4.

Under the action of prestressing force P, the beam will deflect as shown in fig, if it is not restrained at the central support B. A redundant reaction R as shown in fig, develops at the central support, if the beam is restrained at support B, so that deflections are not possible at the supports. As a consequence of this redundant reaction acting downwards, secondary moments, as shown in fig develop in the continuous beam ABC.



Continuity in pre-stressing beam is achieved by applying continuous cable tendon over the various supports. Due to which various moments get generated into the structure and it is used to evaluate the pre-stressing design.Mainly the design of prestressing of beam depends upon two moments, they are; Primary Moment and Secondary Moment.

Primary Moment- The primary moment is the apparent bending moment at a section in a statically indeterminate structure due to actual eccentricity of the tendons from the centroidal axis and obtained by as a product of prestressing force and eccentricity.

Secondary Moment- Secondary moments are additional moments induced at a section of a statically indeterminate structure due to redundant reactions developed as a consequence of prestressing the structure.

A pre-stressing cable in a beam causes the structure to deflect. Unlike the statically determinate beam, where this motion is unrestrained, the movement causes a redistribution of the support reactions which in turn induces additional moments. These are often termed Secondary Moments, but they are not always small, or Parasitic Moments, but they are not always bad. They are normally denoted by M_2.

The calculation of the secondary moments M_2 or the determination of the line of thrust, which are equivalent, can be done in several ways. The development of these methods reflects changes elsewhere in analysis techniques, and of course the adoption of computer techniques.There are three methods for finding secondary moments:-

1. Theorem of Three moment
2. Consistent deformation
3. Tendon reaction

However the thesis will take in consideration the Theorem of Three moment for analysis.

V. EQUATIONS

In this method the free bending moment diagram to be considered is that due to the primary moment represented by the tendon profile, with the longitudinal axis of the member as the horizontal axis. The sagging moments are taken positive and the general form of the three moment equation takes the form-

$$M_{AB} + 2M_{BA} + 2kM_{BC} + kM_{CB} = K_{BA} + kK_{BC}$$

Stiffness ratio = $k = [(I_{AB}/L_{AB})/(I_{BC}/L_{BC})]$

Where, I = Moment of inertia & L = span of beam

For simply supported, $M_{AB} = M_{CB} = 0$
Also k = 1{as the symmetric span}

$$K_{BA} = K_{BC} = (-6P/L^2 \int axdx)$$

Resultant Moment at centre of span = $[-Pe/4 + WdL^2/16]$

Shift of Pressure line from centroidal axis at mid span = $RMc * 1000/P$

Effective reinforcement ratio = [$A_p * fp/b * D^t * f_{ck}$] is calculated.

From coded provision, IS: 1343- 2012, table No. – 11; clause D-1, for the above ratio ($f_{pu}/0.87f_p$) is found out as shown in figure No. – 4.

Therefore $Mu = fpu * Ap * (d - 0.42Xu)$ is calculated.

When elastic distribution of moments is assumed if q_u = ultimate live load then,

$$Mu = 0.125(g + q_u)L2$$

When full redistribution of moments is assumed, if q_u = ultimate live load then and

$$M_{u1} = M_{u2} = M_v$$

Then, $(qu\,L^2/8 + g\,L^2/8) = M_{u2} + 0.5M_{u1})$

From, above formula q_u is calculated.
Where;
M_{u1} = ultimate flexural strength of the support section
M_{u2} = ultimate flexural strength of the centre of span section
Mg = self weight moment
g = uniformly distributed dead load
q_u = ultimate live load
Also find Load factor = q_u/LL

VI. RESULTS AND DISCUSSION

1. From software the beam maximum moments for RCC continuous, Pre-stressed & Post-stressed beams it can be concluded that the moment carrying capacity is more in Pre-stressed and Post-stressed beam, due to the phenomenon of redistribution of moments.

2. The supports need to be analyzed and designed carefully for the positive and negative moments, which are generated due to the prestressing and post-stressing of tendons.

3. It can be seen from the B.M.D for RCC Continuous, Pre-stressed & Post-stressed beams respectively that the moments are more evenly distributed between the centre of span and the supports.

4. It is also concluded from economics based on SOR-2015 (CGPWD) w.e.f. 01.01.2015 as in Result discussion the overall cost of normal RCC beam will be low as compared to pre-stressed beams, which is due to specific special method and instruments required in forming the pre-stressed beams.

5. In the manual designing in Ms-Excel, the values of ultimate/limiting moment of resistance of the section for RCC and Pre-stressed Concrete beam is quite comparable.

6. From the design analysis based on Excel Sheet and Staad.pro software it is seen that Pre-stressed beam structure requires lesser dimension w.r.t normal RCC beam of same Loading conditions. And this is true for all span analysis done in this dissertation thesis i.e. for 6m.

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TABLE NO. – 1 Table 11 of IS: 1343 – 2012

Table 11 Conditions at the Ultimate Limit State for Rectangular Beams with Pre-tensioned Tendons or with Post-tensioned Tendons having Effective Bond

(*Clause* D-1)

Sl No.	$\frac{A_{ps} \cdot f_{pu}}{bd \cdot f_{ck}}$	Stress in Tendon as Proportion of the Design Strength $\frac{f_{pb}}{0.87 f_{pu}}$		Ratio of the Depth of Neutral Axis to that of the Centroid of the Tendon in the Tension Zone x_u/d	
		Pre-tensioning	Post-tensioning with Effective Bond	Pre-tensioning	Post-tensioning with Effective bond
(1)	(2)	(3)	(4)	(5)	(6)
i)	0.025	1.0	1.0	0.054	0.054
ii)	0.05	1.0	1.0	0.109	0.109
iii)	0.10	1.0	1.0	0.217	0.217
iv)	0.15	1.0	1.0	0.326	0.316
v)	0.20	1.0	0.95	0.435	0.414[1)]
vi)	0.25	1.0	0.90	0.542	0.488[1)]
vii)	0.30	1.0	0.85	0.655	0.558[1)]
viii)	0.40	0.9	0.75	0.783	0.653[1)]

[1)] The neutral axis depth in these cases is too low to provide the necessary elongation for developing 0.87 f_{pu} stress level. Hence, it is essential that the strength provided exceeds the required strength by 15 percent for these cases.

Also, from software results, i.e. using STAAD. Pro, the area of steel and the cost of casting the two-span Continuous Beams each of 6m span are graphically represented as:

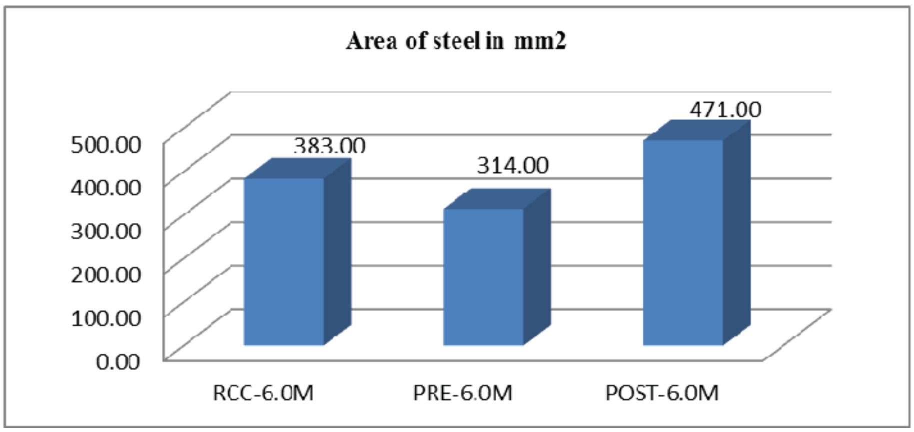


Table No. – 2 SOR-2015 (CGPWD) based economic analysis as per design data in STAAD. Pro for two-span RCC Continuous beam of 6.0m each.

S.No	Particulars of item	Dimensions	Quantity	Rate	Amount
1.	Concrete grade M-40	12mx0.20mx0.30m	0.72cum	4587.50	3303.64
2.	Reinforcement at top	2no.s 12mm dia	21.312Kg	54.50	1161.504
3.	Reinforcement at bottom	2no.s 10mm dia	14.808Kg	54.50	807.036
4.	Stirrups	2 legged 8mm dia @190mm c/c	23.864Kg	54.50	1300.588
5.	Shuttering bottom	12mx0.20m	2.40sqm	202.00	484.80
6.	Shuttering sides	12mx0.30mx2= 7.2 0.20mx0.30mx2= 0.12	7.32sqm	202.00	1478.64
				Total=Rs	8536.20

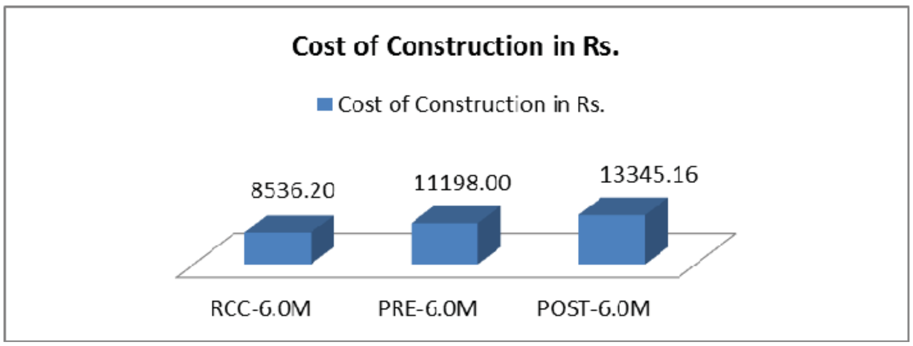
Table No. – 3 SOR-2015 (CGPWD) based economic analysis as per design data in STAAD. Pro for two-span Pre-tensioned Continuous beam of 6.0m each.

S.No	Particulars of item	Dimensions	Quantity	Rate	Amount
1.	Concrete grade M-40 i/c shuttering	12mx0.20mx0.30m	0.72cum	4557.35	3281.29
2.	Reinforcement at top	2no.s 10mm dia	14.808Kg	145.00	2147.16
3.	Reinforcement at bottom	2no.s 10mm dia	14.808Kg	145.00	2147.16

4.	Stirrups	2 legged 8mm dia @180mm c/c	24.982Kg	145.00	3622.39
				Total=Rs	11198.00

Table No. – 4 SOR-2015 (CGPWD) based economic analysis as per design data in STAAD. Pro for two-span Post-tensioned Continuous beam of 6.0m each.

S.No	Particulars of item	Dimensions	Quantity	Rate	Amount
1.	Concrete grade M-40 i/c shuttering	12mx0.20mx0.30m	0.72cum	4557.35	3281.29
2.	Reinforcement at top	4no.s 10mm dia	29.616Kg	145.00	4294.32
3.	Reinforcement at bottom	2no.s 10mm dia	14.808Kg	145.00	2147.16
4.	Stirrups	2 legged 8mm dia @180mm c/c	24.982Kg	145.00	3622.39
				Total=Rs	13345.16



When carried out cost comparison after software based designing, the cost of pre-stressed concrete beam is higher by 31% from RCC.

7. It is revealed in the design that the Pre-stressed beam of 6m span is safe with provided cross-sectional dimension but on increasing of length in span to 9m it considerably becomes prone to failure; as in later case the profile and shift in pressure line for tendon crosses safe limit.

8. Economic analysis is also carried out to know economy of construction based on design methodology used over here in this dissertation thesis i.e. RCC design or Pre-stressed design methods. It is evaluated from the design data's evolved in the designing process by excel and software base analysis, that the beam of lower depth and higher span to depth ratio produces better result in Pre-stressing design than normal RCC method. As later requires the higher area of Steel percentage than previous. But as per prevailing rates based on CGPWD SOR for building works w.e.f. 01.01.2015.

VII. CONCLUSIONS

From the above discussion it might be concluded that, "When beam of small depth to width ratio is designed with specified span to depth ratio; the prestressing method is quite help full in terms of saving percentage of steel and construction under controlled environment with same cross-sectional dimension and loading conditions".

This thesis will be helpful of design of beams, underground structure, communication towers, floating storage and off shore structures, power stations, nuclear reactor vessels and numerous types of bridges using prestressing techniques that requires clear spans ranging from 6m and above. A span of such range in RCC considers a depth that is impractical and uneconomical.

Drawbacks in the conventional RCC have led to the development of Pre-stressed Concrete. This new material about 10 years ago was highly costlier and unfamiliar in the Indian market. But with time and change in the infrastructure of the company, where more and more construction is carried out in the railways, bridges and in industrial areas i.e. where the longer free spans are executable, this material has proved its efficacy over the conventional RCC and hence the rates and cost o construction have reduced to a great extent. This very concept has also been introduced in the Schedule of Rates of the developing state like Chhattisgarh in 2015 w.e.f 01.01.2015. Therefore, in this thesis the cost comparison of 6.0m span continuous RCC and Pre-stressed beam has been carried out to see the economics in the construction.

In this project the study has been done to gain knowledge about the methods designing of beam by conventional RCC methods and Prestressing method, also its comparison by using Staad.pro software tool.

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