"Comparison of Continuous RCC & Prestressed Concrete Beams by Using Limit State Method"

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Abstract - Structural Beam is a horizontal member subjected to loading due to which shearing and straining forces acts on the lateral and axial cross section. The reinforced concrete beam is when subjected to loading it also undergoes changes due to applied loads. The steel is provided at the depth known as effective depth in the overall depth available; the effective depth must coincide with neutral axis or lie above it. The new method used for better result and economic design are introduced namely Prestressed and Post tension.

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 this new method the eccentric value of loading might be assumed and applied for reinforcing bars, wires or tendons. Here the beam member is taken as continuous beam and continuous beam is indeterminate beams, therefore its design is done by as per Indian standard code of practice IS 1343-2012 and IS 456-2000, with the help of Staad.pro Software tools.

Key Words — Prestressing, Shearing, Straining, Effective Depth, Indeterminate.

1. INTRODUCTION

A concise conversation on the difference involving conventional RCC and Pre-tensioning method is desirable due to the design differences in the quality and working technique. Numerous tests have been conducted on conventional RCC and Pre-tensioning and Post-tensioning method but very few tests have been performed on continuous beams assembly. The term Pre-tensioning and Post-tensioning itself describes a wide range of special skill and technique involved in process. Precast concrete consists of concrete that is casted into a specific shape at a location as its in service position. Precast concrete components are reinforced with either conventional reinforcing bars, strands with high tensile strength, or a combination of both. Precast concrete's most dramatic benefit in construction may be the speed with which it can be designed, cast, delivered, and erected. This can ensure that projects stay on schedule and meet tight deadlines. Precast concrete can speed the construction process in a variety of ways. Design of beam by simple conventional method is based on IS: 456-2000 but it has seen that beam design based on pre stressed and post tension methods are IS 1343-2012 far superior in stress bearing and serviceability.

Prestressed concrete is defined as per IS:1343-2012, 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.

The various methods by which pre-compression i.e. stresses are imparted to concrete are classified as follows:

1. Generation of compressive force between the structural elements and its abutments using flat jack.
2. Development of hoop compression in cylindrically shaped structures by circumferential wire binding.
3. Use of longitudinally tensioned steel embedded in concrete or housed in ducts.
4. Use of principle of distortion of a statically indeterminate structure either by displacement or by rotation of one part relative to the remainder.
5. Use of deflected structural steel sections embedded in concrete until the hardening of the latter.
6. Development of limited tension in steel and compression in concrete by using expanding cements.

This method of prestressing has enabled flexibility of structure along with pleasances of style. The structure can be molded and designed as per the intend requirement. Only requirement is skill-full techniques, equipments and labours as the prestressing requires control environment for better fruit full results. Precast construction is cost-effective; as this method has higher rate of construction which can get rid of working days from a construction schedule, resulting in less time to carry financial bonds, lower contractor overhead costs and risk, elimination of expenses for other trades, and reduced subcontractor costs by giving more responsibility to a single-source supplier. Total precast concrete systems save by combining both architectural and structural components into one piece.

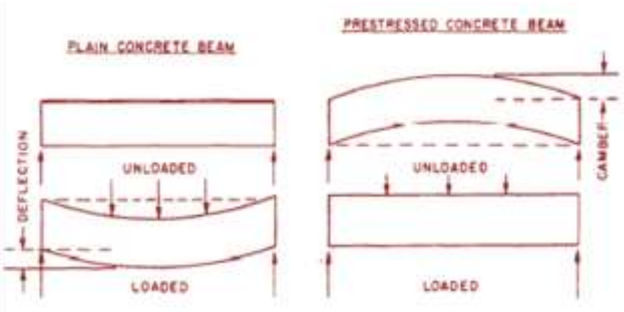


Figure No. – 1.2. Comparison between Plain (RCC) and Prestressed concrete beam.

The depth at a section for continuous beams can be less than a simply supported beam for the same span. Else, for the same depth the span and dimension can be more than a simply supported beam. The continuous beam is economical in material. The bending moment are more evenly distributed between the centre of span & the supports of members. Drop in the shape and size of member results in light structures. The ultimate load-carrying ability is superior in a statically determinate structure due to the observable fact of relocation of moments. Continuity of beams in framed structures leads to increased stability. Continuous beams or girder is created by segmental assembly using pre-cast units connected by prestressing cables. In continuous post-tensioned beams or girders, the curved cables can be suitably placed to resist the span & support stresses and moments. Only one pair of post-tensioning anchorages & a single stressing operation can serve several members is required. The deflections are comparatively small as compared to simply supported spans.

1.1. Objective of Study.

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

Thus for this a continuous beam of simply supported nature having overall span of 12 meter; is designed for both the stressing methods along the conventional method and evaluation on basis of results is to be done. 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.

Advantages of prestressed concrete method:

a. Prestressed member posses better resistance to shear forces due to effect of compressive stresses presence or eccentric cable profile.
b. The use of high strength concrete and steel in prestressed members results in lighter and slender members than is possible with RC members.
c. A prestressed structure deflects appreciably before ultimate failure, thus giving ample warning before collapse.
d. Fatigue strength is better due to small variations in prestressing steel, recommended to dynamically loaded structures.
e. Prestressed beams never fail under direct shear or punching shear failure.

Variation in (L/h) ratio has a slight influence on the value of the increase in the tendon stress, with a tendency to reduce as (L/h) increases. The reduction in tendon stress at the low Effect of concrete strength Increase in concrete strength results in an increase in the prestressing force in the external tendons at ultimate, as can be seen from Also, by comparing the effect of concrete strength with that of the other factors considered, concrete strength can be seen to be one of the main factors influencing the ultimate tendon stress.

The increase in the tendon stress in the beam subjected to loads at the third span is 32% greater than that in the beam with a single load at mid span. This is because, during loading, cracks started to appear on the beam surface and spread as the load increased. This continued up to the formation of the plastic hinge where the strain concentrated and stress increased up to failure.

2. LITERATURE REVIEW

Rajamoori Arun Kumar et. Al. [1] with new technology growth the conventional bridge has been replaced by cost effective structural system. PSC T-beam, which is wide acceptance in freeway and bridge systems due to their structural efficiency, good stability, serviceability, economical in construction and pleasing aesthetics view. In compare with PSC T-beam, RCC T- beam geometry is simple and does not complicated in construction. The selection of economical and construction of structural system is depending on the result.

Ahmed Ghallab and A.W. Beebyet. Al. [2] studied During loading, the internal bonded steel assisted the external pre-stressing tendons in resisting the applied moment up to yielding of the internal steel, in the paper Factors affecting the external prestressing stress in externally strengthened prestressed concrete beam.

Vaibhav G Tejani et. Al. [3] review for Study of Prestressing Systems for all Structural Element; concluded Pre –stressed concrete is economical for large span than RCC work but for small span quite expensive.

Visvesvaraya, H C and N Raghavendra, et. Al. [4] presented paper on "continuity in prestressed concrete construction" at Seminar on problems of prestressing, Madras; 1970, and described its effects.

As per **Indian standard codes IS: 1343. 2012** et. Al. [5] For pre-tensioned members and for post-tensioned members with effective bond between the concrete and tendons, values of f_{pb} and x_u. Its hall be ensured that the effective prestress, f_{pe} after all losses is not less than $0.45f_{pu}$, where f_{pu} is the characteristic tensile strength of tendon. Prestressing tendons in the compression zone should be ignored in the strength calculations.

Chris Burgoyne et. Al. [6] concluded that "The successful design of continuous prestressed concrete beams cannot be divorced from the techniques used to analyze the structure, and the way these have developed in the 60 years since the first indeterminate structures were built is a fascinating reflection on the way structural analysis has developed over the same period".

Ankit Sahu, et. Al. [7] Cost Comparison between RCC & Post-Tensioned Prestressed Beams Spanning 26m. found that, for span 26m Post-Tensioned Pre-stressed concrete beam is 34% cheaper than RCC beam.

A. R. Mundhada et. Al. This work includes the design and estimates of continuous R.C.C. beams and continuous pre-stressed concrete beams of various spans. The best way is to select the type of construction, depending on the circumstances and type of structure. 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.

Sucharita De et. Al. [8] "Economics of RCC and Prestressed Concrete Beams and Design in Ms-Excel" This method is 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.

3. METHODOLOGY AND ANALYSIS

3.1. Method of Design used:

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.

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 M2.

The calculation of the secondary moments M2 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 methodsfor finding secondary moments:-

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

However; we will take in consideration the Theorem of Three moment for analysis. 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, MAB = MCB = 0
Also k = 1{as the symmetric span}

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

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 = $[A_p * fp/b * D' * f_{ck}]$ is calculated.

From coded provision, IS: 1343- 2012, table No. – 11; clause D-1, for the above ratio (fpu/0.87fp) 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 qu = ultimate live load then, Mu = 0.125(g + qu) L2
When full redistribution of moments is assumed, if qu = ultimate live load then and

$$M_{u1} = M_{u2} = M_u,$$

Then,

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

From, above formula qu is calculated.
Where;

Mu1 = ultimate flexural strength of the support section
Mu2 = ultimate flexural strength of the centre of span section
Mg = self weight moment
g = uniformly distributed dead load
qu = ultimate live load
Also find Load factor = q_u/LL

3.2. Dimensional and Design specification of continuous beam.

a. Dimensional data:

Span of beam	=	12 mt{6 mt each}
Width of beam	=	200 mm
Depth of beam	=	300 mm

b. Design data:

Type of reinforcement	=	Bars[fy = 500]
Grade of concrete	=	M40
Grade of steel	=	Fe-500
Dead load	=	as per self weight.
Live load	=	3 kN/m
Prestressing force	=	200 kN
Class of beam	=	Type 2.

c. Structure figure.

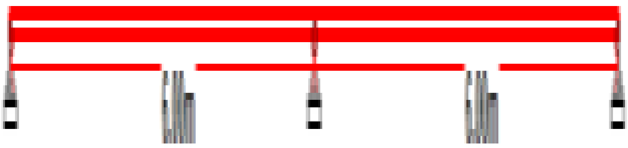


Figure No. – 3.1 Continuous Beam designed.

3.3. Nature of prestress parasitic moments

Consider a three-span continuous beam that has been released by hinges over the restraints to create three statically determinate spans. The three equal spans are subjected to uniform loads. The free bending moment at the centre of each part of span, $M_{max} = wl^2/8$, where w is the load per meter and l; the span, and the bending moment at any point may be called M_i so. The beams will deflect, and the end rotation of each beam $\theta = M_{max}$ ⍰ l/3EI.

If the spans are to be made continuous, hogging moments must be applied at each internal support such that the rotations of the beam ends become compatible. The hogging moments for a three-span beam, for this particular case of three equal spans, a value of $wl^2/10$ at each internal support; that is 80 per cent of the free bending moment.

It might be called the 'continuity moments', the values at any point being Mc. The total moment at any point along the continuous beam will be the sum of the free bending moment and the continuity moment. The uniform loads on the statically determinate spans may be replaced by parabolic prestressing cables anchored on the neutral axis at the beam ends, which apply; a uniform upwards load on the beams. The prestress force P and the eccentricity at mid-span ec may be chosen to give an upwards distributed force = w kN/m, and hence to produce exactly the same bending moments and beam end rotations, although of the opposite sign, as the externally loaded beams described.

The free bending moment at the centre of each span is Pec and the moment at any point is Pe. In order to make the beams continuous, numerically the same moments as for the distributed loads, that is 80 per cent of Pec but of opposite sign, must be applied at each internal support.

These continuity moments are called the 'parasitic moments' or Mp. The prestress moment at any point in a continuous beam is then Pe + Mp, continuity moments due to prestress are of exactly the same nature as the continuity moments due to external loads.

However, whereas the free bending moments and the continuity moments dueto external loads are linked by the laws of statics and are consequently considered together as 'the bending moment', it is convenient to consider Pe and Mp separately. The eccentricity of the prestress is under the control of the designer, who may thus vary the resulting Mp between certain limits.

3.4. Design of RCC vs Prestressed continuous beam by using Excel Sheet, for 6 m span

S.No.	Design Standard and Specification	Values RCC Beam	Values Prestressed Beam
1	Effective Depth	270 mm	250 mm
2	$K_{BA} = K_{BC} = (-6P/L*L\int exdx)$	-	30 kNm
3	Secondary moment = Mb	-	15
4	Resultant Moment at central support	22.95 kNm	15.25 kNm
5	Effective reinforcement ratio	0.58	0.36
6	Mu	77.57	105.57 kNm
7	q_u = ultimate live	27	21.96 kN/m
8	load factor against collapse	9.21	11.23
9	Area of Reinforcement Ap	314	452

4. RESULT ANALYSIS

Result Analysis of Continuous Prestressed beam of 6 m span by Staad.pro Software.

Table No. -1, Pre-Stressed Beam Maximum Beam End Forces Summary.

	Beam	Node	L/C	Axial Fx (kN)	Shear Fy (kN)	Shear Fz (kN)	Torsion Mx (kNm)	Bending My (kNm)	Bending Mz (kNm)
Max Fx	1	1	1:LOAD CASE 1	**0.000**	3.377	0.000	0.000	0.000	0.000
Min Fx	1	1	1:LOAD CASE 1	**0.000**	3.377	0.000	0.000	0.000	0.000
Max Fy	2	2	4:COMBINATION LOAD	0.000	**14.373**	0.000	0.000	0.000	15.241
Min Fy	1	2	4:COMBINATION LOAD	-0.000	**-14.373**	-0.000	-0.000	-0.000	15.241
Max Fz	1	1	1:LOAD CASE 1	0.000	3.377	**0.000**	0.000	0.000	0.000
Min Fz	1	1	1:LOAD CASE 1	0.000	3.377	**0.000**	0.000	0.000	0.000
Max Mx	1	1	1:LOAD CASE 1	0.000	3.377	0.000	**0.000**	0.000	0.000
Min Mx	1	1	1:LOAD CASE 1	0.000	3.377	0.000	**0.000**	0.000	0.000
Max My	1	1	1:LOAD CASE 1	0.000	3.377	0.000	0.000	**0.000**	0.000
Min My	1	1	1:LOAD CASE 1	0.000	3.377	0.000	0.000	**0.000**	0.000
Max Mz	1	2	4:COMBINATION LOAD	-0.000	-14.373	-0.000	-0.000	-0.000	**15.241**
Min Mz	1	2	3:LOAD CASE 3	-0.000	2.486	-0.000	-0.000	-0.000	**-4.974**

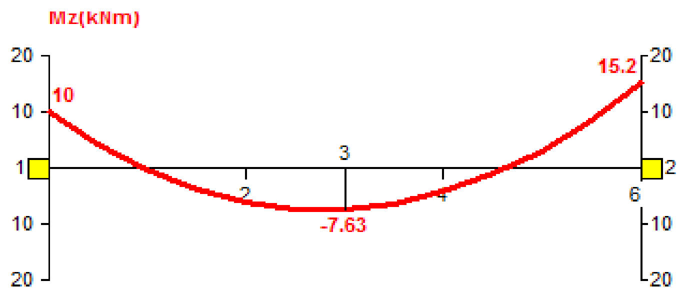
Table No. -2, Post- Stressed Beam Maximum Beam End Forces Summary.

	Beam	Node	L/C	Axial Fx (kN)	Shear Fy (kN)	Shear Fz (kN)	Torsion Mx (kNm)	Bending My (kNm)	Bending Mz (kNm)
Max Fx	1	1	3:LOAD CASE 3	**200.000**	0.000	0.000	0.000	0.000	10.000
Min Fx	1	1	1:LOAD CASE 1	**0.000**	3.377	0.000	0.000	0.000	0.000
Max Fy	2	2	4:COMBINATION LOAD	200.000	**16.869**	0.000	0.000	0.000	30.215
Min Fy	1	2	4:COMBINATION LOAD	200.000	**-16.869**	-0.000	-0.000	-0.000	30.215
Max Fz	1	1	1:LOAD CASE 1	0.000	3.377	**0.000**	0.000	0.000	0.000
Min Fz	1	1	1:LOAD CASE 1	0.000	3.377	**0.000**	0.000	0.000	0.000
Max Mx	1	1	1:LOAD CASE 1	0.000	3.377	0.000	**0.000**	0.000	0.000
Min Mx	1	1	1:LOAD CASE 1	0.000	3.377	0.000	**0.000**	0.000	0.000
Max My	1	1	1:LOAD CASE 1	0.000	3.377	0.000	0.000	**0.000**	0.000
Min My	1	1	1:LOAD CASE 1	0.000	3.377	0.000	0.000	**0.000**	0.000
Max Mz	1	2	4:COMBINATION LOAD	200.000	-16.869	-0.000	-0.000	-0.000	**30.215**
Min Mz	1	1	1:LOAD CASE 1	0.000	3.377	0.000	0.000	0.000	**0.000**

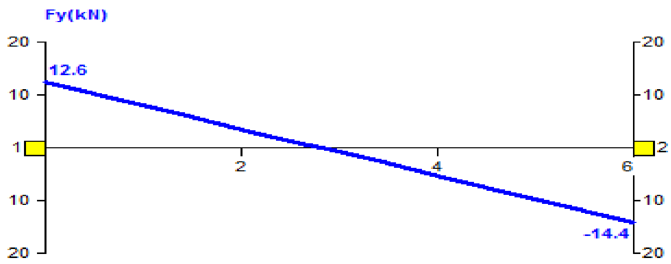
Table No. -3, RCC Beam Maximum Beam End Forces Summary.

	Beam	Node	L/C	Axial Fx (kN)	Shear Fy (kN)	Shear Fz (kN)	Torsion Mx (kNm)	Bending My (kNm)	Bending Mz (kNm)
Max Fx	1	1	1:LOAD CASE 1	**0.000**	3.377	0.000	0.000	0.000	0.000
Min Fx	1	1	1:LOAD CASE 1	**0.000**	3.377	0.000	0.000	0.000	0.000
Max Fy	2	2	3:COMBINATION	0.000	**16.869**	0.000	0.000	0.000	20.215
Min Fy	1	2	3:COMBINATION	-0.000	**-16.869**	-0.000	-0.000	-0.000	20.215
Max Fz	1	1	1:LOAD CASE 1	0.000	3.377	**0.000**	0.000	0.000	0.000
Min Fz	1	1	1:LOAD CASE 1	0.000	3.377	**0.000**	0.000	0.000	0.000
Max Mx	1	1	1:LOAD CASE 1	0.000	3.377	0.000	**0.000**	0.000	0.000
Min Mx	1	1	1:LOAD CASE 1	0.000	3.377	0.000	**0.000**	0.000	0.000
Max My	1	1	1:LOAD CASE 1	0.000	3.377	0.000	0.000	**0.000**	0.000
Min My	1	1	1:LOAD CASE 1	0.000	3.377	0.000	0.000	**0.000**	0.000
Max Mz	1	2	3:COMBINATION	-0.000	-16.869	-0.000	-0.000	-0.000	**20.215**
Min Mz	1	1	1:LOAD CASE 1	0.000	3.377	0.000	0.000	0.000	**0.000**

Graph No. 1- Bending Moment for Prestressed continuous beam of 6m span.



Graph No. 2- Shear force for Prestressed continuous beam of 6m span.



5. RESULT DISCUSSION.

In the Design Analysis for two span RCC continuous beam each of 6.0 m span, the bending moment value for intermediate support is 26.10 kNm and for the beam of similar design value specifications when analyzed in Staad. Pro it is 20.20kNm. This moment is indeed a necessary value for designing and due to which the values of area of steel required as per manual is 235.00sq-mm but provided as 314.00sq-mm and as per software is 274.20sq-mm respectively. Similar design value when analyzed for Pre-stressed & Post-stressed in Staad. Pro it gives area of steel requirement as 231.00sq-mm and 393.00sq-mm respectively for the bending moment at intermediate support evaluated as 15.2kN & 30.2kN.

From the deign 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.

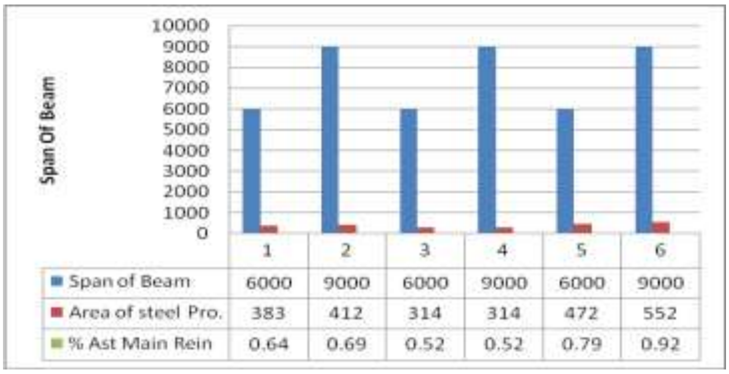
It is revealed in the design that the Pre-stressed beam of 6m span is safe with provided cross-sectional dimension but on increasing of length in span to 9m it considerably becomes prone to failure; as in later case the profile and shift in pressure line for tendon crosses safe limit. Also, from Excel sheet it is found that' the total resultant moment at mid support of Pre-stressed continuous beam of 6m span is 15.25kNm, where; as total resultant moment at mid support of Pre-stressed continuous beam of 9m span is 45.56kNm.Which indicates that there is systematic increment of resultant moment at mid support, approximately of 10.00 kNm per meter run increased in span length.

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. The value of neutral axis for Pre-stressed continuous beam of 6m is 196 mm and for RCC continuous beam of 6m span is 200 mm, which indicates higher requirements of construction materials.

Table No. – 4. SOR-2015(CGPWD) based economic analysis as per design data in Ms. Excel Sheet.

S. No	Particulars of item	Area of steel mm² (Avg)	Length of Beam, mm.	Quantity Kg.	Rate Rs.	Amount Rs.
1	RCC Cont. beam	314	12000	42.6	54.50	2322
2	Pre-Stressed Cont. beam	452	12000	15	145	2175
2	Post-Stressed Cont. beam	552	12000	22.5	145	3263

Graph No. – 3. Percentage Area of steel for different spans optimization of Staad.pro.



6. CONCLUSIONS

The conservative conclusion may be categorised as follows:

1. Conventional RCC member requires more steel reinforcement than Pre-stress members.
2. Amount of stress and moment is subsidised by pre-stressing method in comparison with conventional method.
3. Eccentric loading of stress profile can be maintained in pre-stress and post-stress way of reinforcement to regulate moments of resistance.
4. The load carrying capacity of member is enhanced by eccentric loading method as this improvises bending moment resistant in pre-stressing method.
5. The moment carrying capacity gets increased as the positions of moment get shifted from loading position area towards restraints span.

It is also concluded from economic analysis based on SOR-2015 (CGPWD) 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 a pre-stressed beams.

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