COST OPTIMIZATION OF PRESTRESSED CONCRETE BEAMS

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Abstract- The main objective of every structural engineer is to design an optimum structure. It can be achieved by intuition, experience and repeated trails. The cost optimization plays a vital role in today’s competitive industry. The conventional ways of design development largely generate excessive material usage, due to very high design margins resulting in consumption of more materials by the structures and buildings. Due to the recent advancements in the field of computation in the past two decades, the efficiency of the computation is becoming more accurate, efficient and affordable to everyone. This availability of the computation power given the designer an opportunity for evaluating multiple options during the initial phases of design using Genetic Logarithms, MS-Solver and other programming tools.

This research presents the cost optimization technique by the Non-Linear programming GRG- Nonlinear method in MS- Solver. In this study design procedure and cost optimization of the rectangular simply supported Prestressed concrete beams of Type- I, II and III based on the specifications of the IS 1343:2012 and IS 456:2000. The optimized results are obtained that are economical, reliable and practical.

The main objective of the study is to find out the optimum breadth, depth and Area of Prestressing steel. Which are the major constituents of the cost of the prestressed rectangular concrete beam subjected to varied uniformly distributed load from 5KN/m to 40KN/m varying lengths from 5m to 30m. The cost of the beam is expressed as a function of the quantity of concrete and steel, formwork and grade of concrete. The cost function is chosen as the objective function for the problem and the variables are the breadth, depth of the section and area of prestressing steel. The Optimum beam results obtained have to satisfy the strength and serviceability conditions as per the design code IS 1343:2012 and IS 456:2000, hence these are the constraints for the

Keywords: Cost Optimization, Constraints, Objective Function, Design Variables, Minimum Weight, MS Solver, IS 456,IS 1343.

I.INTRODUCTION

The history of prestress ways long back, starting with the force fitting of the metal bands to the wooden barrel as shown in fig 1.1 and fitting of the rubber tyres to the wooden wheels fig 1.2 shows that the prestressing has been practicing from ancient times. The reinforced concrete was developed by combining two different materials Concrete and steel. Concrete that is strong in compression and resists compressional stresses and weak in tension and cannot resists tensile stress steel that is strong in tension and weak in compression combined with concrete to increase the performance of the structural member.

The prestressed concrete principal has been widely used for the design of beams, bridges and in deep beams. The sections, that are prestressed were comparatively light in weight and were suited for the serviceability and architectural design criteria when compared to the conventional reinforced concrete sections. Prestressing the concrete with steel eliminates the cracks in the concrete that allows the concrete capable enough to bear the reversal of stresses, impact loadings, vibrations and shock. Further, it also improves the durability and fatigue strength of the member.

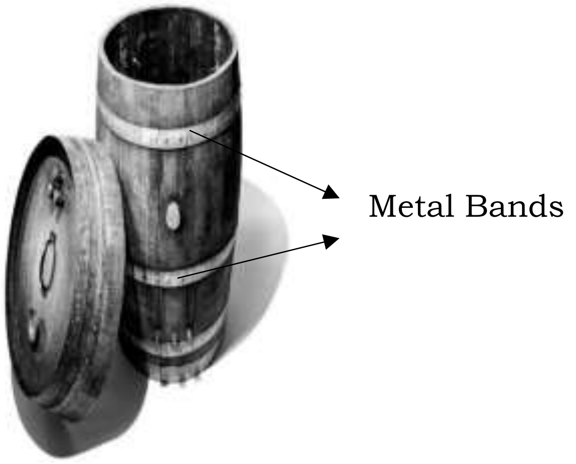


Fig 1.1: Prestressed metal band fitted to the wooden barrel

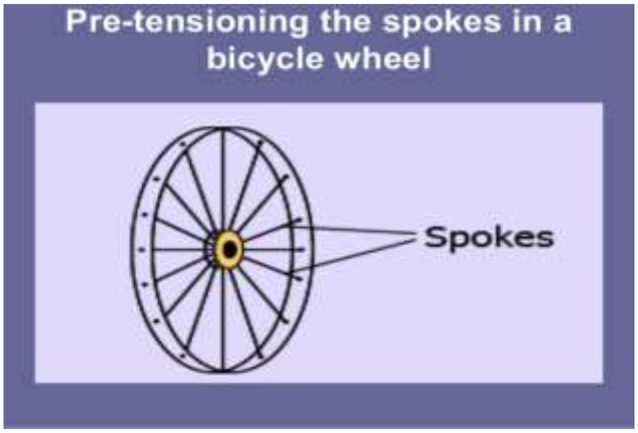


Fig 1.2: Pre-tensioning the spokes in a bicycle wheel

As per IS 1348:2012 the classification of the structures is as follows. If members made up of precast units, no tension is allowed at any stage at mortar or concrete joints. For a member which is free of joints, the tensile stress shall not exceed the values specified below for the 3 types of members as per clause no.24.2.1 of IS 1343:2012.

- **TYPE 1:** Prestressed concrete sections in which no tensile stress is permitted, under the service load.
- **TYPE 2:** The tensile stress shall not exceed 3N/mm^2.However, where part of service load is temporary in nature, this value may be exceeded by 1.5N/mm^2, provided under the permanent component of the service load the stress remains compressive.
- **TYPE 3:** The members in which cracking is permitted, it may be assumed that the concrete section is uncracked, and that hypothetical tensile stresses exist at the maximum size of the crack.

II. Optimization:

Optimization is a technique adopted to choose an alternative with the most cost effective or high performance from several possible alternatives under the given constraints, choosing the maximum desirable factors and minimizing the undesirable factors. In the present days, Optimum design of the structures has been the most important topic for the researchers in the field of the Structural Engineering. A design engineer's goal is to obtain an "optimal solution" for the structure design under the various geometrical and the structural limitations without increasing the cost for the construction of the structure. The optimal solution is nothing but obtaining an economical structure without impairing the functional performance of the structure.

Optimization is the process of obtaining the best result for any given circumstances. It is widely applicable in design, construction and maintenance of any engineering systems. Engineers have the choice of choosing the traditional or the advanced programming methods to obtain the optimized solution. A number of optimization methods been developed for solving different types of optimization problems like optimization using calculus, Linear Programing, Non-Linear Programming, Dynamic Programming, Integer Programming and Advanced optimization techniques such as Generic Algorithms, Multi objective optimization.

III. Procedure of optimization: The optimization procedure consists of the following phases:

- Formulation of the Problem statement
- Identification of the variables
- Deriving the Constraints
- Formulation of the Objective function
- Identifying the optimization technique
- Deriving the solution
- Performing sensitivity Analysis

IV. Variables:

A variable is a set of unknown value which alters the value of the objective function. The variables may be set of resources, time taken for a work, numbers that alter depending upon the design limitations. The variables depend on constrains of the problem. In a structural engineering problem the most common variables which are the geometrical dimensions such as length, breadth, width, and the design parameters like clear cover, area of steel and concrete etc. The design Variables are

X_1= Breadth of the beam
X_2 = Depth of the beam
X_3= Area of the Prestressing Steel

V. Objective Function:

In the structural design the objective function is usually the cost minimization. The objective function is a function of the design variables satisfying the design constrains provides the choice in deciding the acceptable design function. The cost function is mostly depended upon the variables, which is obtained during the design process. The cost function depends upon the various parameters like cost and quantity of the concrete and the steel, formwork, grade of the concrete and steel etc.

Mostly the cost function has to be the minimum value.

C.F (cost function) = min $\{Q_c * C_c + Q_{Ast} * C_{Ast} + Q_f * C_f\}$

Where,

Q_c = Quantity of Concrete Volume (m^3)
Q_{Ast}=Quantity of Area of the steel (mm^2)
Q_f =Quantity of Formwork (m2)

C_c =Cost of the Concrete per Cu.m
C_{ast} = Cost of the steel per Ton
C_f = Cost of the formwork per Sq.m

VI. Constraints:

Constraints are the set of the conditions to be satisfied by the variables and have to satisfy the conditions of the structural performance as per the prescribed design code. Usually constrains are the upper or lower boundary limits to be satisfied by the obtained desired variables while solving the problem. In a structural engineering problem the commonly used constrains are minimum and maximum percentage of steel in the section, deflection, shear strength, spacing of the strripus, bars etc.

i. Minimum depth

The IS: 456:2000 clause 23.2.1 specifies that the minimum span to effective depth ratio must be less than 20 for simply supported beams for spans up to 10 meters and for spans above 10 m, the (L/d) value has to be multiplied by 10/span in meters.

C_1 = minimum depth (d_{min}) [$d_{min} \leq \frac{L}{20}$]

ii. Minimum breadth

The IS: 456:2000 Fig. 1 specifies that theminimum beam width must not be less than 150mm depending upon the factor of resistance for the fire including the cover to the reinforced bars in the beams.

C_2 = minimum breadth (b_{min}) [$b_{min} \leq 150$ mm]

iii. Minimum depth to width ratio:

As per the thumb rule the maximum depth to width ratio should be in the range of 1.5 to 2 and 3 in some case if the beam is subjected to repeated loadings.

C_3= Minimum depth to width ratio **[**$\frac{D}{b} \geq 2$ **]**

iv. Maximum depth to width ratio:

As per the thumb rule the maximum depth to width ratio should be in the range between 1.5 to 2 and 3 in some case if the beam is subjected to repeated loadings.

C_4 = Maximum depth to width ratio **[**$\frac{D}{b} \geq 3$ **]**

v. Minimum Area of Prestressing steel:

The IS 1343:2012 clause 19.6.3.3specifies that the minimum area of the prestressing longitudinal steel should be 0.2% of the total area of the concrete.

C_5 = Minimum Area of Prestressing steel **[** $A_{ps\ min} \geq 0.2\%(bD)$

vi. Maximum Area of Prestressing steel:

The detailing of the reinforcement in the prestressed concrete should generally meet the requirements specified in IS: 456:2000 which says that the maximum reinforcement in the section must not exceed 0.04 times the total area of the concrete.

C_6 = Maximum Area of Prestressing steel **[** $A_{ps\ max} \leq 0.04\ (bD)$ **]**

vii. Live load deflection constant:

As per the IS 1343: 2012 and IS 456:2000 the maximum deflection (δ_{max}) must be less than the permissible deflection (δ_{perm}).

C_7 = Live load deflection **[**$\delta_{max} \leq \delta_{perm}$ **]**

Where, $\delta_{max,ll} = \frac{5\, Wll * L\text{^}4}{384 * Ec * Ic}$ and $\delta_{perm} = \frac{L}{300}$

W_{ll} = Live load

I_c= Momentum of Inertia

E_c= Modulus of elasticity of concrete

L = Span or Length of the beam

viii. Dead load deflection constant:

As per the IS 1343: 2012 and IS 456:2000 the maximum deflection (δ_{max}) must be less than the permissible deflection (δ_{perm}).

C_8 = Dead load deflection **[**$\delta_{max} \leq \delta_{perm}$**]**

Where, $\delta_{max,dl} = \frac{5*Wdl*L^4}{384*Ec*Ic}$ and $\delta_{perm} = \frac{L}{250}$

W_{dl} = Dead load

I_c = Momentum of Inertia

E_c = Modulus of elasticity of concrete

L = Span or Length of the beam

ix. Dead load deflection constant:

As per the IS 1343: 2012 and IS 456:2000 the maximum deflection (δ_{max}) must be less than the permissible deflection (δ_{perm}).

C_9 = Upward deflection due to the Prestressing force **[**$\delta_{max} \leq \delta_{perm}$**]**

Where, $\delta_{max,pi} = -\frac{5*Pi*e*L^4}{48*Ec*Ic}$ and $\delta_{perm} = \frac{L}{350}$

P_i = Prestressing Force after losses

I_c = Momentum of Inertia

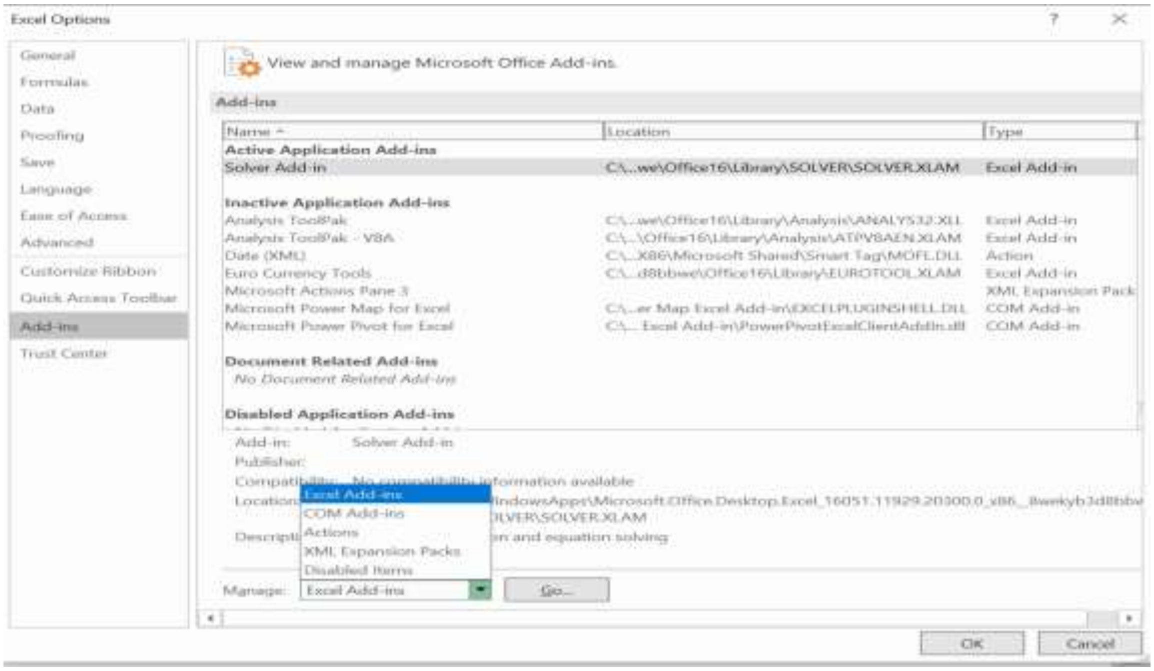
E_c = Modulus of elasticity of concrete

L = Span or Length of the beam

e = Eccentricity

VII.MS Solver Solution

The Solver Add-In in MS Excel 2019 offers three techniques for solving optimization problems: Simplex method for linear problems, Generalized Reduced Gradient (GRG) algorithm for optimizing smooth nonlinear problems, and Evolutionary method for non-smooth nonlinear problems, which utilized genetic algorithms. The optimal beam design is a nonlinear problem and either the GRG Nonlinear or the Evolutionary options can be used in MS Excel. However, given the non-convex nature of the problem, none of the two techniques guarantees the global optimum solution. In fact, depending on the starting values of the decision variables, Solver may fail to converge to a feasible solution at all. The following are the steps involved



Name ▴	Location	Type
Active Application Add-ins		
Solver Add-in	C:\...we\Office16\Library\SOLVER\SOLVER.XLAM	Excel Add-in
Inactive Application Add-ins		
Analysis ToolPak	C:\...we\Office16\Library\Analysis\ANALYS32.XLL	Excel Add-in
Analysis ToolPak - VBA	C:\...\Office16\Library\Analysis\ATPVBAEN.XLAM	Excel Add-in
Date (XML)	C:\...X86\Microsoft Shared\Smart Tag\MOFL.DLL	Action
Euro Currency Tools	C:\...d8bbwe\Office16\Library\EUROTOOL.XLAM	Excel Add-in
Microsoft Actions Pane 3		XML Expansion Pack
Microsoft Power Map for Excel	C:\...er Map Excel Add-in\EXCELPLUGINSHELL.DLL	COM Add-in
Microsoft Power Pivot for Excel	C:\... Excel Add-in\PowerPivotExcelClientAddIn.dll	COM Add-in
Document Related Add-ins		
No Document Related Add-ins		
Disabled Application Add-ins		

Add-in: Solver Add-in

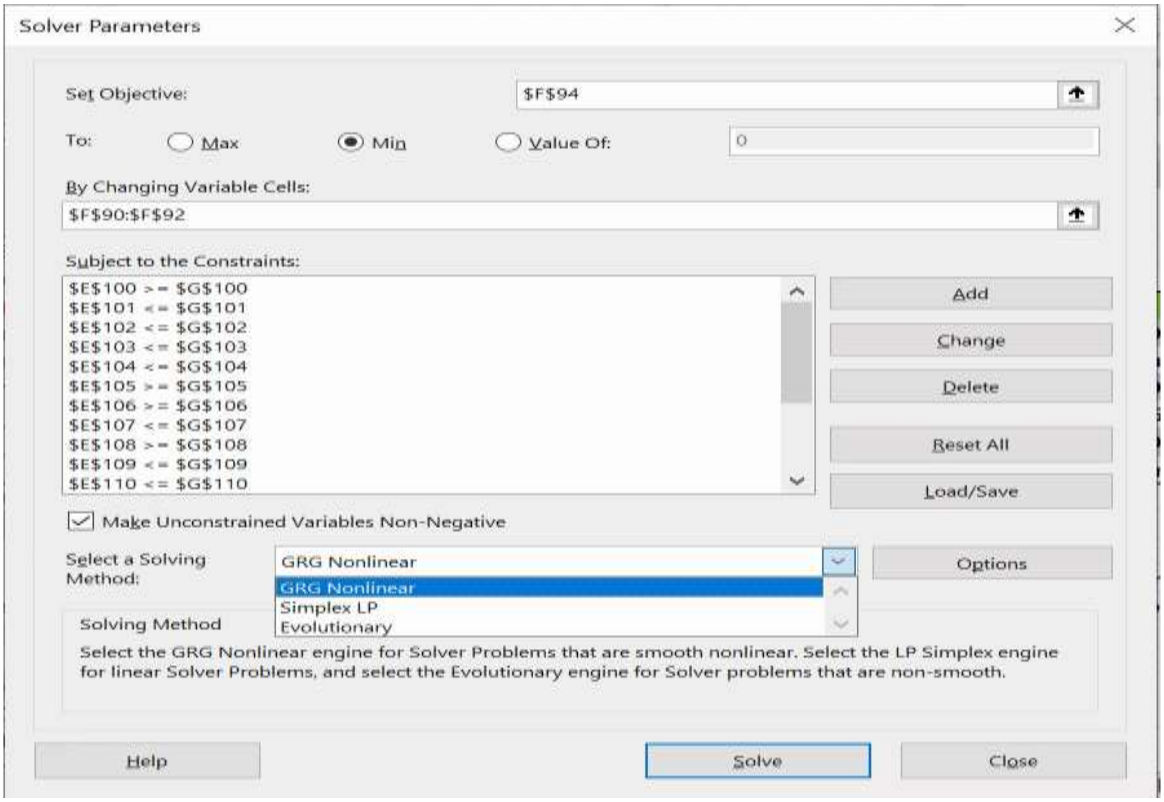
Publisher:

Compatibility: No compatibility information available

Location: indowsApps\Microsoft.Office.Desktop.Excel_16051.11929.20300.0_x86__8wekyb3d8bbwe
OLVER\SOLVER.XLAM

Descripti n and equation solving

Manage: Excel Add-ins



Solver Parameters

Set Objective: $F$94

To: ○ Max ● Min ○ Value Of: 0

By Changing Variable Cells: $F$90:$F$92

Subject to the Constraints:

$E$100 >= $G$100
$E$101 <= $G$101
$E$102 <= $G$102
$E$103 <= $G$103
$E$104 <= $G$104
$E$105 >= $G$105
$E$106 >= $G$106
$E$107 <= $G$107
$E$108 >= $G$108
$E$109 <= $G$109
$E$110 <= $G$110

☑ Make Unconstrained Variables Non-Negative

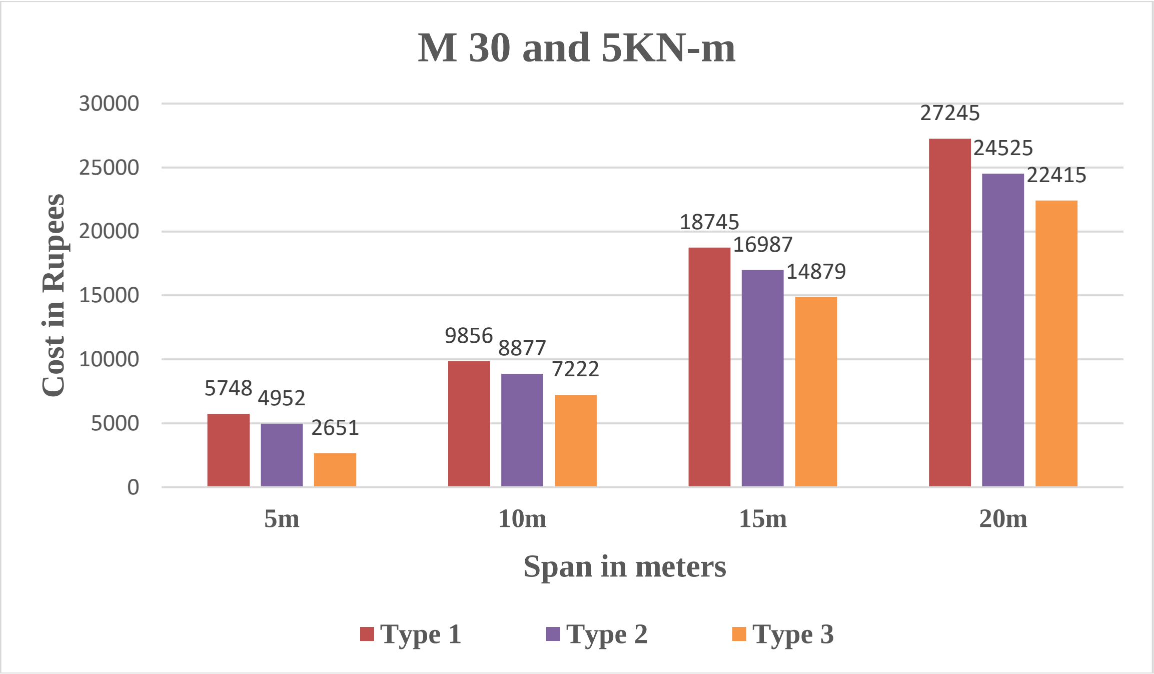
Select a Solving Method: GRG Nonlinear

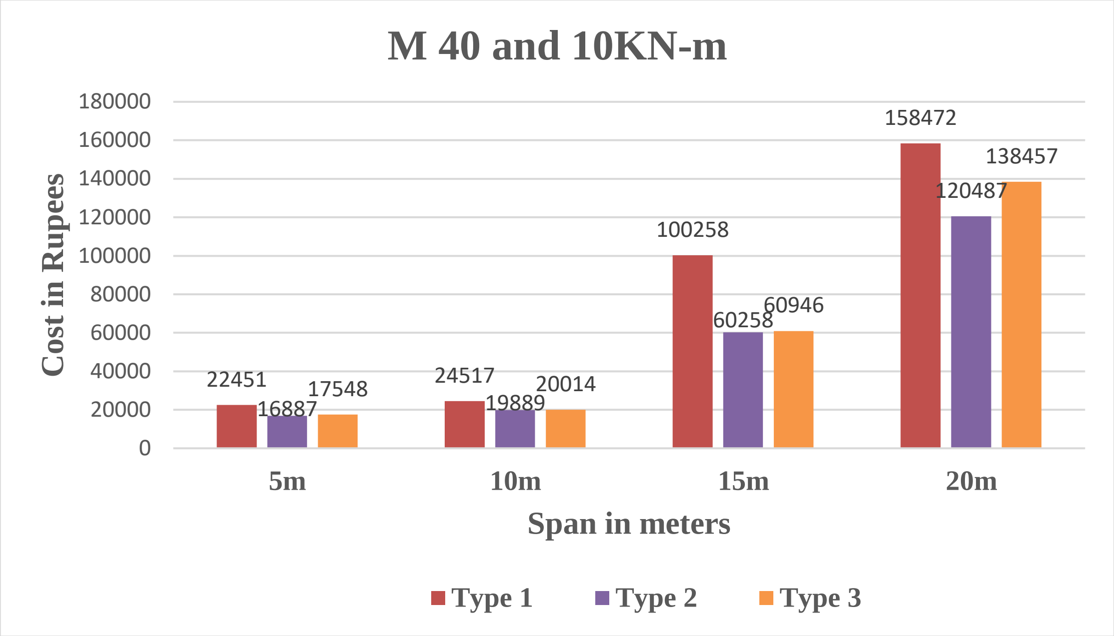
Solving Method

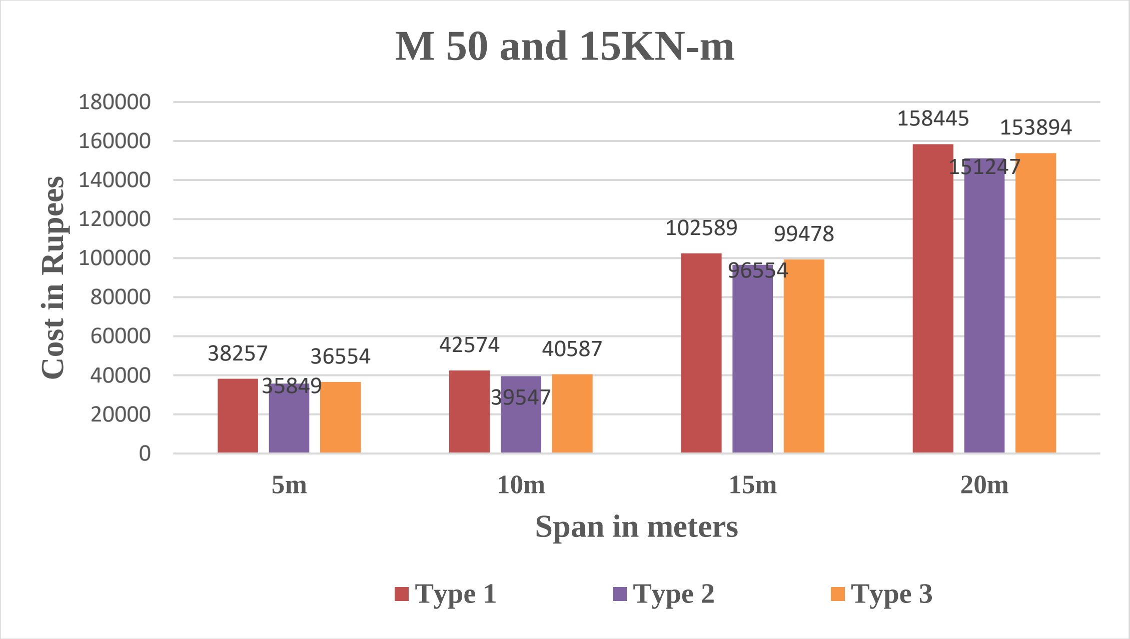
Select the GRG Nonlinear engine for Solver Problems that are smooth nonlinear. Select the LP Simplex engine for linear Solver Problems, and select the Evolutionary engine for Solver problems that are non-smooth.

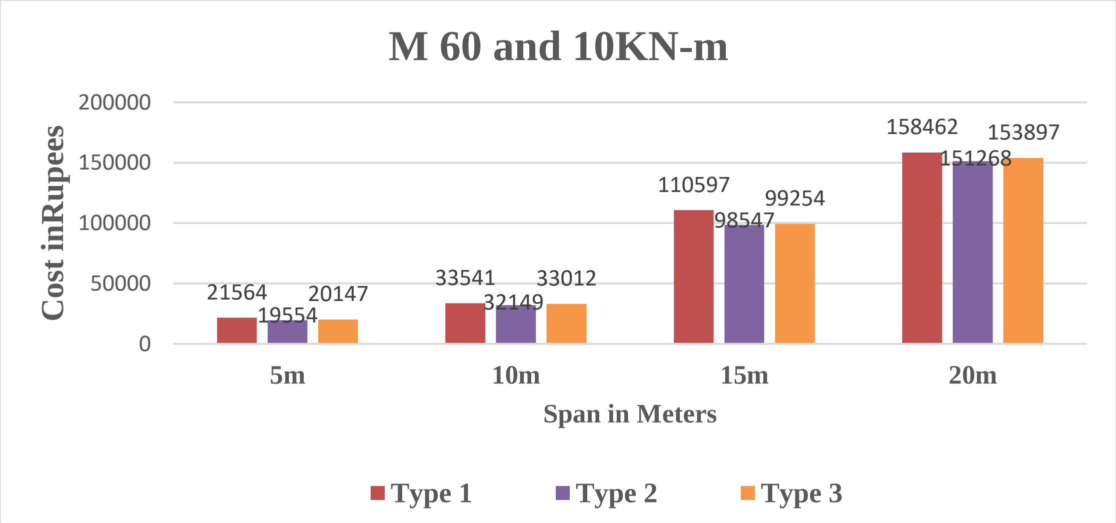
VIII. Results

In the present study, the preliminary design of the sections is done and the results are given as input to the Excel solver sheet by Excel-Spreadsheets and Solver- Add is used for the Cost optimization of the sections. The following graphs were plotted between the Cost on Y- axis and Spans on X- axis.




M 40 and 10KN-m
Cost in Rupees
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
22451
16887
17548
24517
19889
20014
100258
60258
60946
158472
120487
138457
5m
10m
15m
20m
Span in meters
Type 1
Type 2
Type 3


M 50 and 15KN-m
Cost in Rupees
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
38257
35849
36554
42574
39547
40587
102589
96554
99478
158445
151247
153894
5m
10m
15m
20m
Span in meters
Type 1
Type 2
Type 3


M 60 and 10KN-m
Cost inRupees
200000
150000
100000
50000
0
21564
19554
20147
33541
32149
33012
110597
98547
99254
158462
151268
153897
5m
10m
15m
20m
Span in Meters
Type 1
Type 2
Type 3

IX.Conclusions:

1) The Cost of the Type-2 section is less when compared to that of the Type-1 and Type-3 sections. The cost of type -2 section is less than 10% of the Type-3 and 20% less than the Type-1 section.
2) The Cross-sectional area of the Type-2 section is also small compared to that of the Cross-sectional area of the Type-1 and 3 sections. A reduction of 22.48% and 15.49% in cross sectional area was observed in Type-2 sections compared to that of Type-1 and Type-3 respectively.
3) The amount of prestressing force is also smaller for Type-2 members when compared to that of Type-1 and Type-3 sections by 21.65% and 12.86% respectively making the section more cost efficient.

X. References:

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