PARAMETRIC STUDY AND ANALYSIS OF PRE-STRESSED CONCRETE BOX GIRDER BRIDGE

Rashmi R Koushik[1], Shilpa Patil[2], Rakesh R[3]

[1]MTech Student, Department of Civil Engineering, Global Academy of Technology, Bengaluru -560098
[2]Asst. Professor, Department of Civil Engineering, Global Academy of Technology, Bengaluru -560098
[3]MTech Student, Department of Civil Engineering, Global Academy of Technology, Bengaluru -560098

Abstract

The importance of highway bridges in a modern transportation system aims in providing safety and quality in construction. This paper discusses the Parametric study and Analysis of Prestressed Concrete Box-girder bridge and focuses on the Structural Analysis comparison of Simply Supported, Continuous and Overhang bridges for the same loading conditions to find the most economical cross-section for various spans. A three span bridge model with four lanes is considered. Span length being 30m, 36m, 45m, 51m, 60m, 66m, 75m, 81m, 90m, 96m, 105m, 111m and 120m respectively. The live load assigned for the bridge model is IRC Class A Wheeled loading. The Code considered for bridge design is the Indian code (IRC-2000). Analysis is carried out using the computer software CSi Bridge v17.0.

Keywords— Box Girder; Pre-stressing; Simply Supported; Continuous; Overhang; Deflection; IRC Class A loading.

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1. INTRODUCTION

A bridge is that structure built for carrying the road / rail movement or other moving loads. A box girder bridge is either a Structural steel, Pre-stressed concrete, Reinforced concrete or composite section bridge in which the girders are hollow box shape. It is either trapezoidal, circular, square, rectangular or tailor made in cross-section. Pre-stressing is defined as the initiation of compressive force to the concrete to restrain the stresses resulting from an applied load. For longer spans, Pre-stressed box girders are chosen as the depth of the box girder can be reduced remarkably when compared to normal I-girders. When compared to T-beam Girder Bridge, longer spans can be incorporated in a Box girder bridge, thereby resulting in lesser number of piers and also economy. The closed cell within the box girder has higher torsional stiffness and strength than an open section. This is the main basis for choosing a box girder configuration. A Simply Supported bridge has many individual spans and is usually used for adjacent spans of different dimensions or different geometries. Each span is supported with roller/hinges at the ends upon which the loads act. A Continuous bridge is a statically indeterminate structure continuous for two or more intermediate supports. A Overhang bridge has a portion of the deck built additionally over the beams. It consists of a Simply Supported central span. The overhang is provided such that fewer number of beams are incorporated. The dimension of the overhang being 1/4 or 1/5 of the total span. This reduces the bending moment to about 50% of the moment for a simply supported beam. The main aim of this project is to keep the deflection within the permissible limits for each of the support conditions.

2. MATERIAL PROPERTIES AND ALLOWABLE STRESS

- **Material properties:**
  1) Grade of concrete: M45 = 45 N/mm^2
  2) Young's modulus (E) = $3.35*10^7$ kN/m^2
  3) Poisson's ratio (υ) = 0.2
  4) Shear Modulus (G) = $1.39*10^7$ kN/m^2
  5) Coefficient of thermal expansion (A) = $5.5*10^{-6}$
  6) Specific comp. strength of concrete (f_c^1) = 45 kN/m

- **Tendon Properties:**
  1) Type of pre-stressing – Post tensioning
  2) Diameter of the pre-stressing cable: ASTM 0.5
  3) Pre-stressing Strand: 13mm (0.5"strand)
  4) Modulus of Elasticity: Eps = $1.968*10^8$ kN/m²
  5) Elastic shortening stress: 20684.274 kN/m²
  6) Creep stress: 34473.79 kN/m²
  7) Shrinkage stress: 48263.31 kN/m²
  8) Steel relaxation stress: 34473.79 kN/m²
  9) Curvature coefficient: 0.15
  10) Wobble coefficient: $6.56*10^{-4}$
  11) Anchorage Slip: $6.35*10^{-3}$
  12) Coefficient of thermal expansion (A) = $1.17*10^{-5}$
  13) Minimum yield stress = F_y = $1689.9*10^3$ KN/m²
  14) Minimum tensile stress = F_u = $1861.58*10^3$ KN/m²
  15) Total number of tendons: 1

- **Rebar properties:**
  1) Grade of steel: HYSD500 = 500 N/mm^2
  2) Young's modulus (E) = $2.00*10^8$ kN/m^2
  3) Poisson's ratio (υ) = 0.3
  4) Coefficient of thermal expansion (A) = $1.17*10^{-5}$
  5) Minimum yield stress = F_y = $5*10^5$ KN/m^2
  6) Minimum tensile stress = F_u = $5.45*10^5$ KN/m^2

- **Abutment properties:**
  1) Abutment depth = 2.3m
  2) Abutment width = 0.5m
  3) Cross section area = 1.15m^2
  4) Moment of Inertia about 3 axis = 0.507 m^4
  5) Moment of Inertia about 2 axis = 0.024 m^4
  6) Section modulus about 3 axis = 0.4408 m^3
  7) Section modulus about 2 axis = 0.0958 m^3

- **Column properties:**
  1) Circular column diameter = 1.5m
  2) Cross section area = 1.7671m^2
  3) Moment of Inertia about 3 axis = 0.2485 m^4
  4) Moment of Inertia about 2 axis = 0.2485 m^4
  5) Section modulus about 3 axis = 0.3313 m^3
  6) Section modulus about 2 axis: 0.3313 m^3

- **Bent properties:**
  1) Bent cap depth = 4m
  2) Bent cap width = 2m
  3) Cross section area = 8m^2
  4) Moment of Inertia about 3 axis = 10.66 m^4
  5) Moment of Inertia about 2 axis = 2.66 m^4
  6) Section modulus about 3 axis = 5.33 m^3
  7) Section modulus about 2 axis = 2.66 m^3

3. CROSS SECTION SPECIFICATION (As per IRC: 18 – 2000)
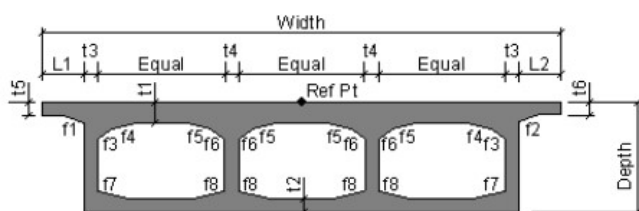
Fig 1.0 – Cross section of the deck

1) Type of structure: Multi-cell PSC Box girder
2) Depth of box girder = 2.3m
3) Total top width of box girder = 17.2m
4) Total bottom width of box girder = 14.2m
5) Thickness of web(t3, t4) = 0.35m
6) Thickness of bottom slab(t2) = 0.25m
7) Thickness of top slab(t1) = 0.35m
8) Diaphragm thickness = 0.3m
9) Diaphragm depth = 1m
10) Number of cells = 3
11) Number of interior girders = 3
12) Vertical fillet dimension(f1 to f8) = 0.15m
13) Horizontal fillet dimension(f1 to f8) = 0.6m
14) Left overhang length(L1) = 1.5m
15) Right overhang length(L2) = 1.5m

4. LOADING ON BOX GIRDER

Dead Loads – It consists of fixed loads, weight of the superstructure, including own weight of the member.

Superimposed Dead Loads – It includes footpaths, earth-fills, formwork, ballast, signs, wearing surface, pipes, conduits, water-proofing cables and other externally installed accessories on the structure.

Prestressing force – Varies with respect to the span.

Vehicle Live Loads - The vehicles passing over the bridge are considered. Vehicle live loads are classified as Class 70R, IRC Class AA (tracked and wheeled), IRC Class A and IRC Class B loading. In this project, IRC Class A loading is considered.
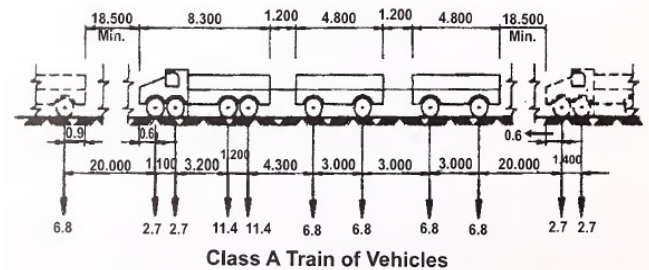
Fig 1.1 – IRC Class A loading
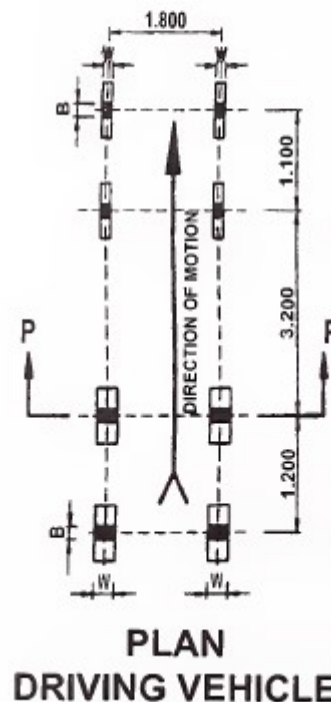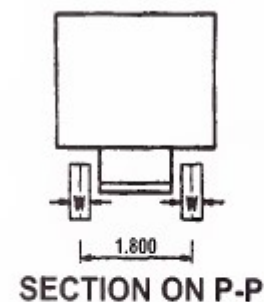
Fig 1.2 – Plan of loading of vehicles

Fig 1.3 – Assigned Live load values using the software
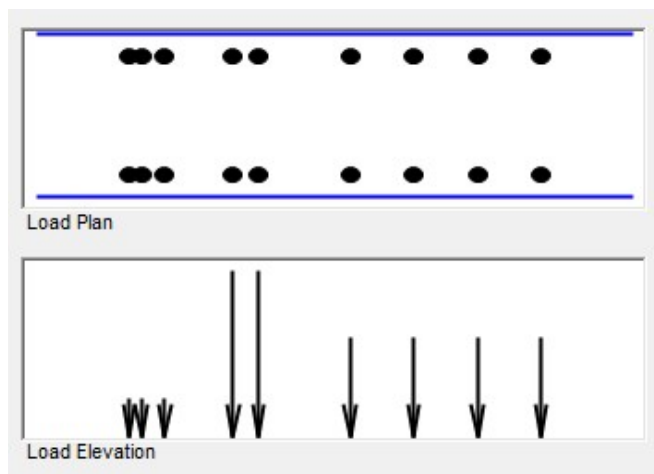
Fig 1.4 – Plan and Elevation of the assigned Live loads

Load Combinations

Table 1.1 - Load combination

Without Pre-stressing force,			
Loads	Dead	Super-imposed Dead	Live
Value	1	1	1

With Pre-stressing force,				
Loads	Dead	Super-imposed Dead	Live	Prestress
Value	1	1	1	1

5. ANALYSIS

NOTE: DIMENSIONS IN X AXIS - m
DIMENSIONS IN Y AXIS - m

5.1 SPAN – 30m

5.1.1 Simply Supported
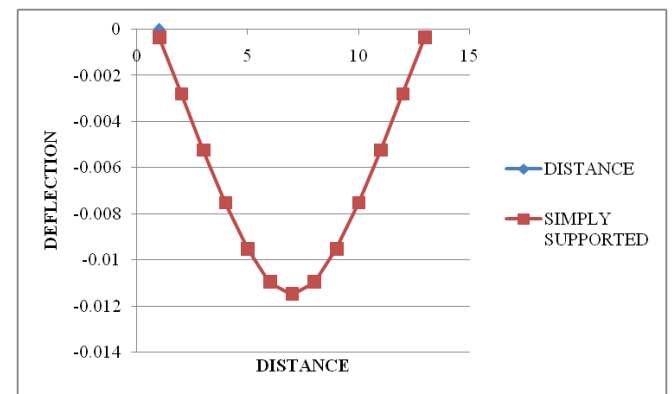
Chart 1.0 - Deflection Vs Distance for Simply supported bridge without Pre-stressing force for 30m span.
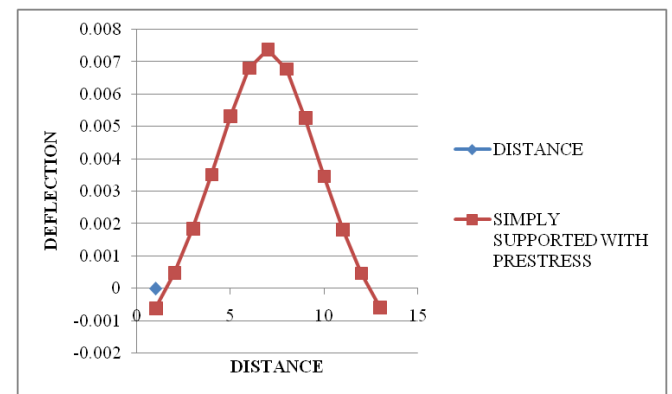
Chart 1.1 - Deflection Vs Distance for Simply supported bridge with Pre-stressing force for 30m span.
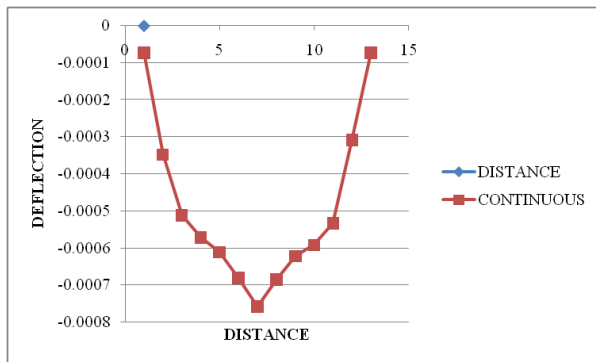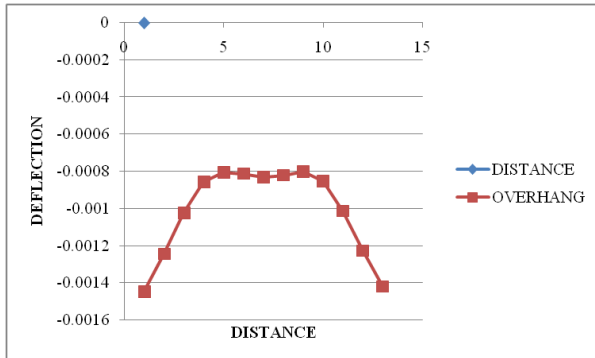
5.1.2 Continuous

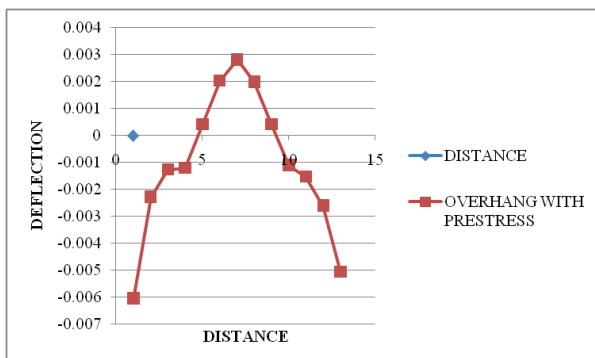**Chart 1.2 -**Deflection Vs Distance for Continuous bridge without Pre-stressing force for 30m span.
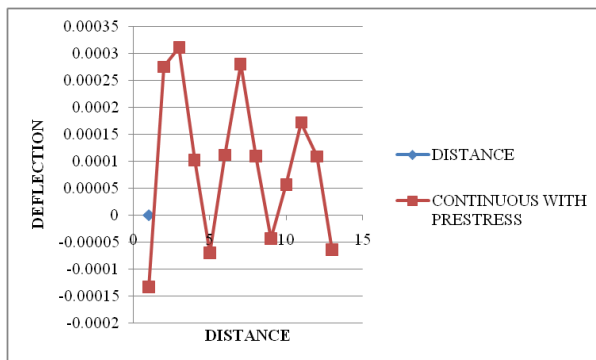
Chart 1.3 - Deflection Vs Distance for Continuous bridge with Pre-stressing force for 30m span.
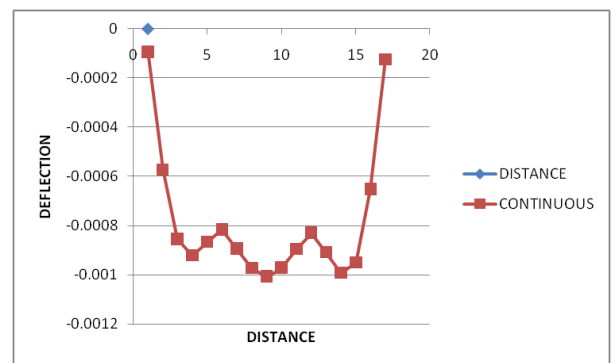
5.1.3 Overhang
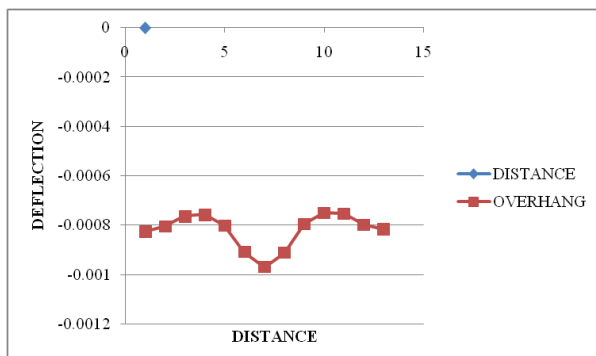
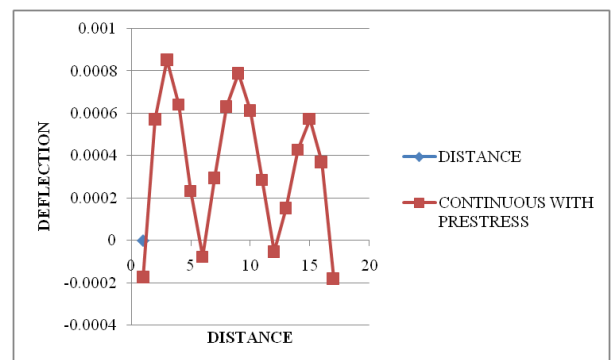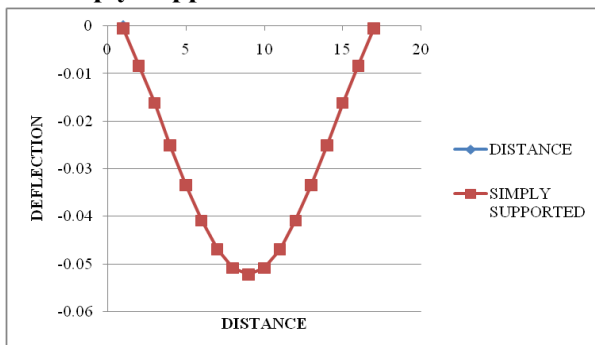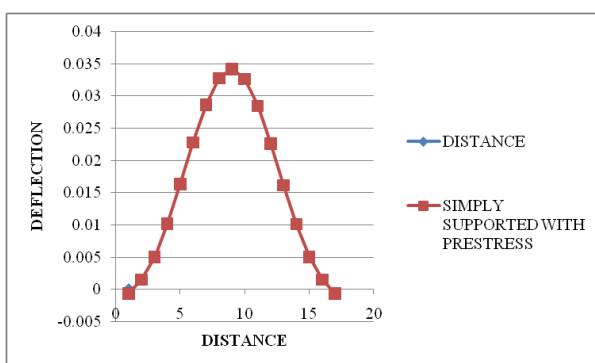**Chart 1.4 -** Deflection Vs Distance for Overhang bridge without Pre-stressing force for 30m span.
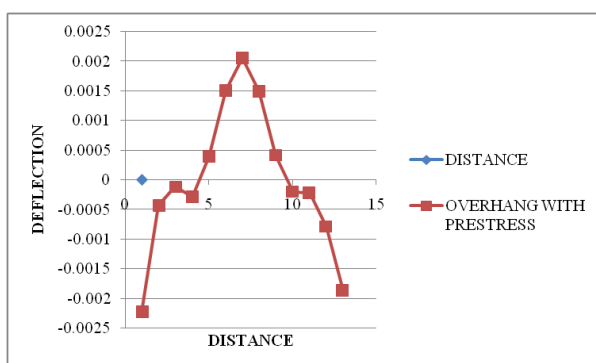
Chart 1.5 - Deflection Vs Distance for Overhang bridge with Pre-stressing force for 30m span.

5.2 SPAN – 36m
5.2.1 Simply Supported
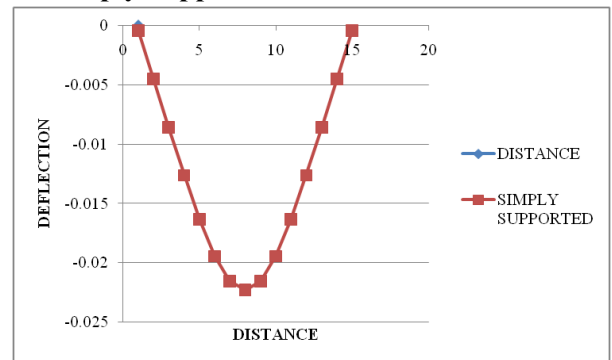
Chart 1.6 - Deflection Vs Distance for Simply supported bridge without Pre-stressing force for 36m span.
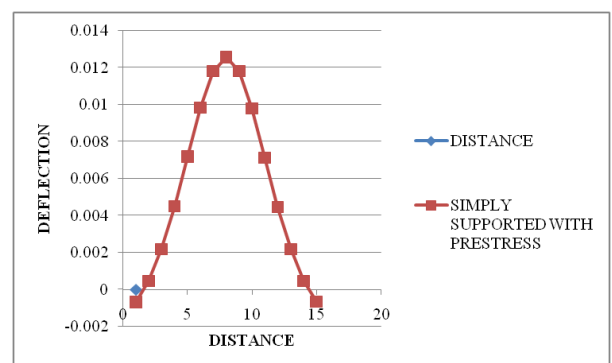
Chart 1.7 - Deflection Vs Distance for Simply supported bridge with Pre-stressing force for 36m span.

5.2.2 Continuous
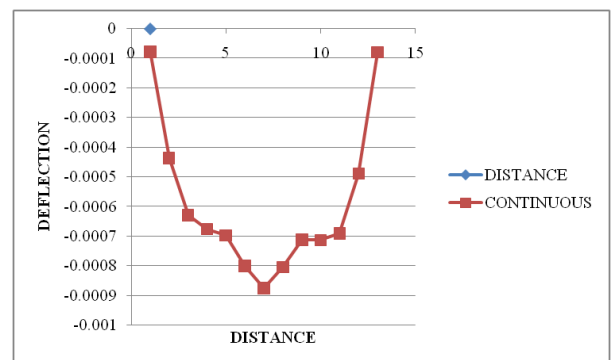
Chart 1.8 - Deflection Vs Distance for Continuous bridge without Pre-stressing force for 36m span.
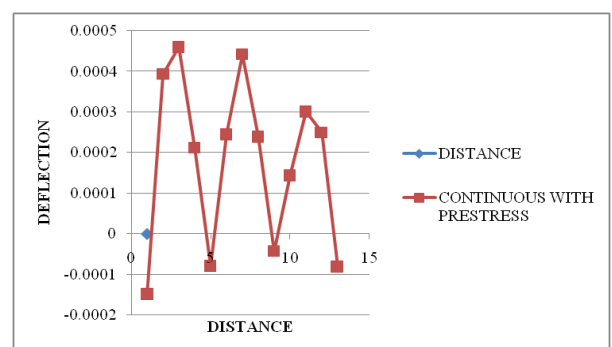
Chart 1.9 - Deflection Vs Distance for Continuous bridge with Pre-stressing force for 36m span.

5.2.3 Overhang

Chart 2.0 - Deflection Vs Distance for Overhang bridge without Pre-stressing force for 36m span.

Chart 2.1 - Deflection Vs Distance for Overhang bridge with Pre-stressing force for 36m span.

5.3 SPAN – 45m
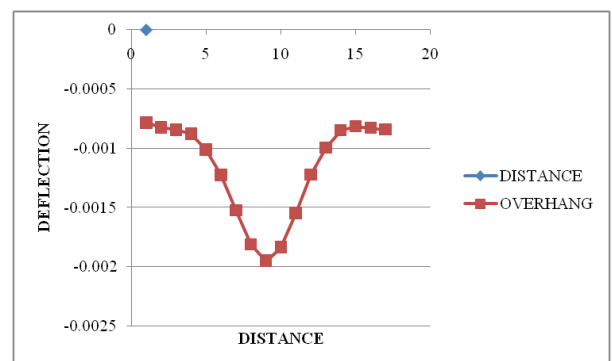### 5.3.1 Simply Supported

Chart 2.2 - Deflection Vs Distance for Simply supported bridge without Pre-stressing force for 45m span.
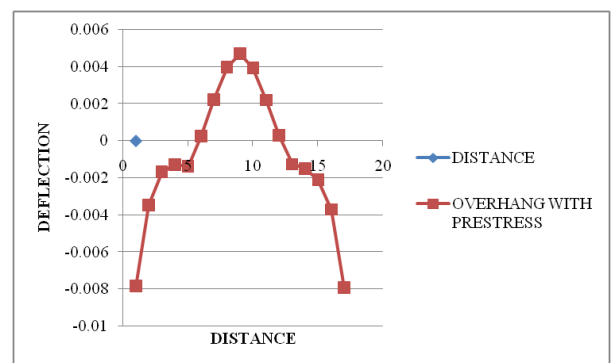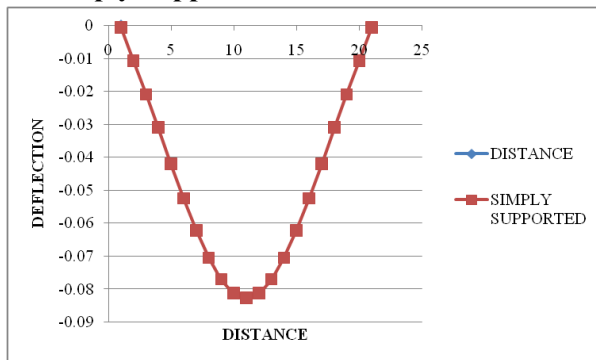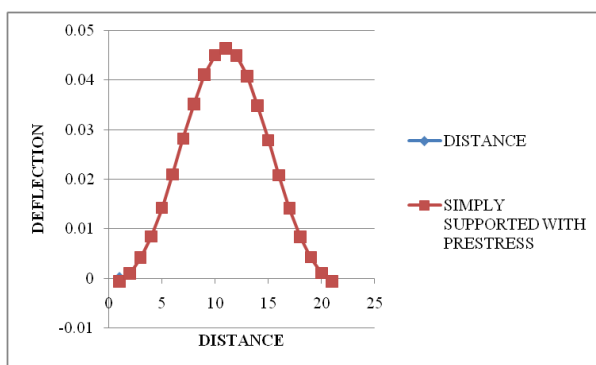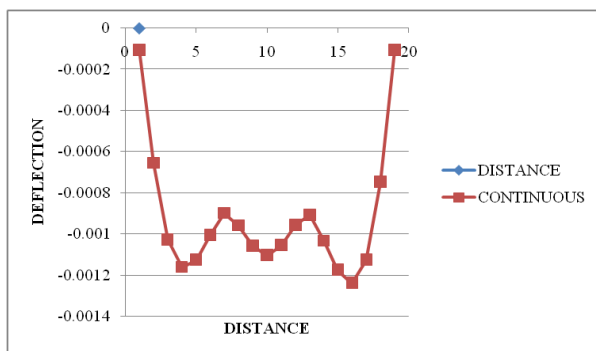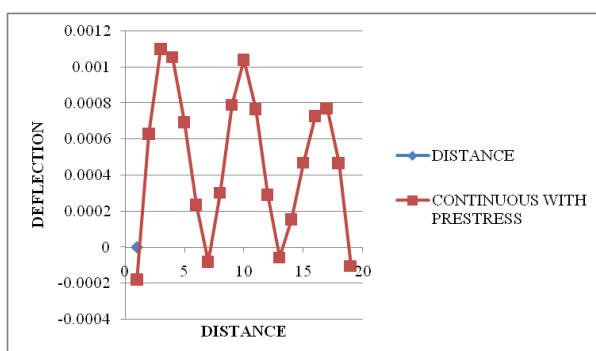

Chart 2.3 - Deflection Vs Distance for Simply supported bridge with Pre-stressing force for 45m span.
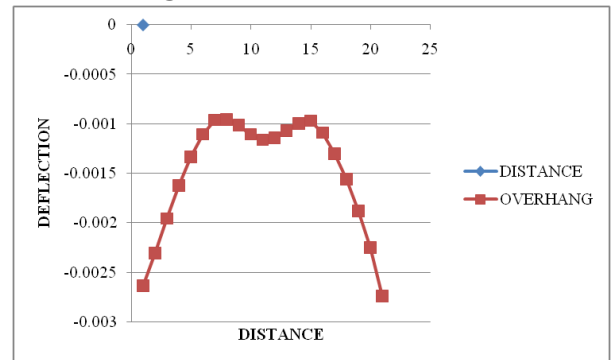
5.3.2 Continuous

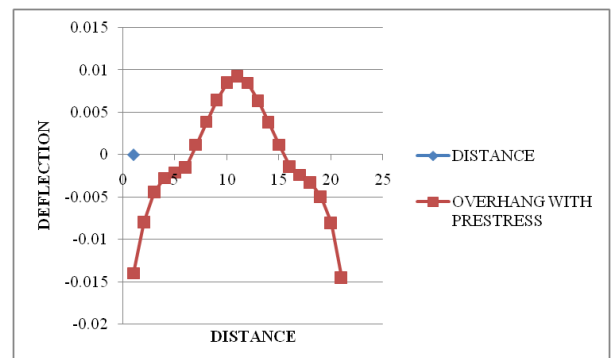**Chart 2.4 -** Deflection Vs Distance for Continuous bridge without Pre-stressing force for 45m span.

Chart 2.5 - Deflection Vs Distance for Continuous bridge with Pre-stressing force for 45m span.
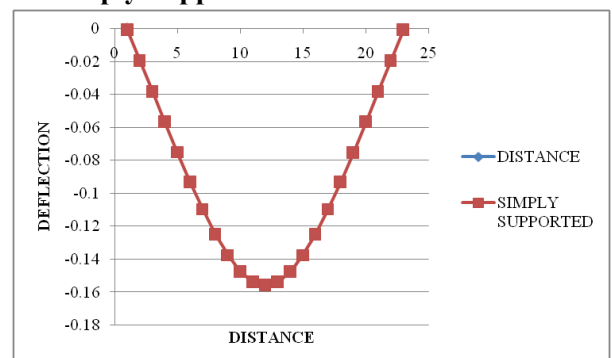
5.3.3 Overhang

Chart 2.6 - Deflection Vs Distance for Overhang bridge without Pre-stressing force for 45m span.
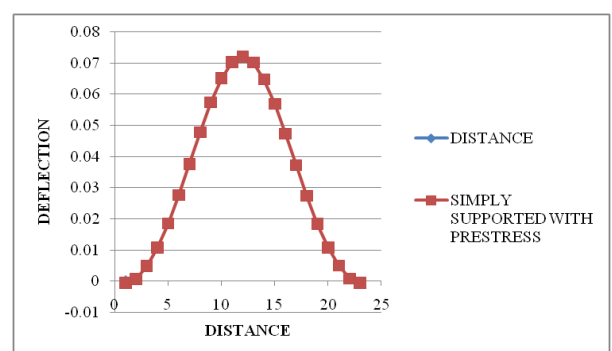

Chart 2.7 - Deflection Vs Distance for Overhang bridge with Pre-stressing force for 45m span.

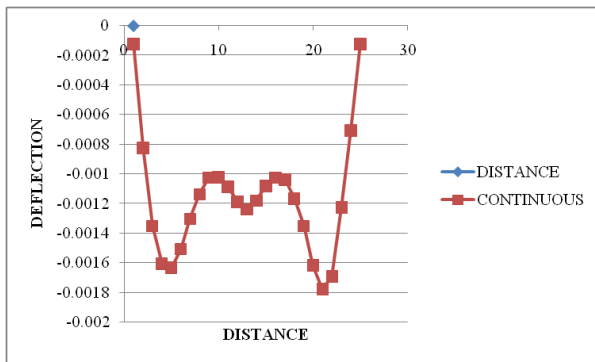## 5.4 SPAN – 51m
5.4.1 Simply Supported

Chart 2.8 - Deflection Vs Distance for Simply supported bridge without Pre-stressing force for 51m span.
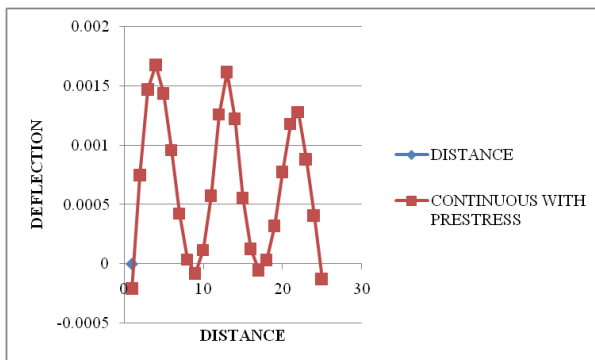

Chart 2.9 - Deflection Vs Distance for Simply supported bridge with Pre-stressing force for 51m span.

5.4.2 Continuous

Chart 3.0 - Deflection Vs Distance for Continuous bridge without Pre-stressing force for 51m span.

Chart 3.1 - Deflection Vs Distance for Continuous bridge with Pre-stressing force for 51m span.

5.4.3 Overhang

Chart 3.2- Deflection Vs Distance for Overhang bridge without Pre-stressing force for 51m span.

Chart 3.3 - Deflection Vs Distance for Overhang bridge with Pre-stressing force for 51m span.

5.5 SPAN – 60m
5.5.1 Simply Supported

Chart 3.4 - Deflection Vs Distance for Simply supported bridge without Pre-stressing force for 60m span.

Chart 3.5 - Deflection Vs Distance for Simply supported bridge with Pre-stressing force for 60m span.
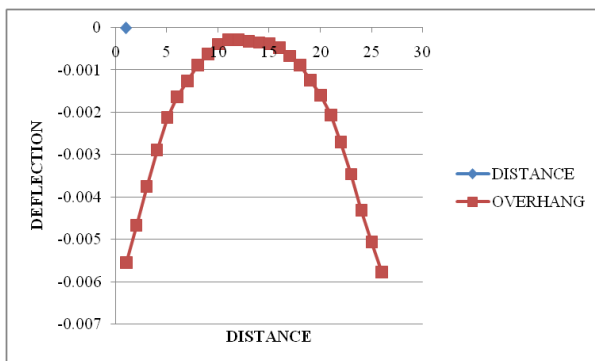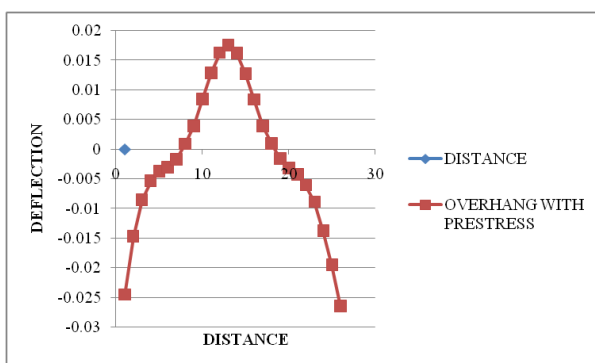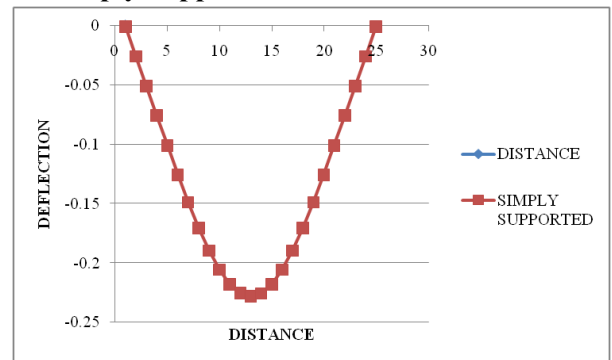
5.5.2 Continuous

Chart 3.6- Deflection Vs Distance for Continuous bridge without Pre-stressing force for 60m span.

Chart 3.7 - Deflection Vs Distance for Continuous bridge with Pre-stressing force for 60m span.

5.5.3 Overhang

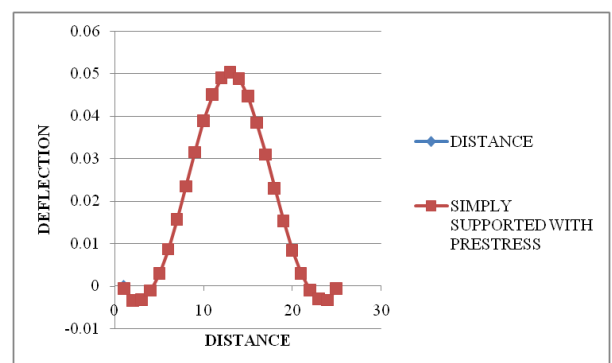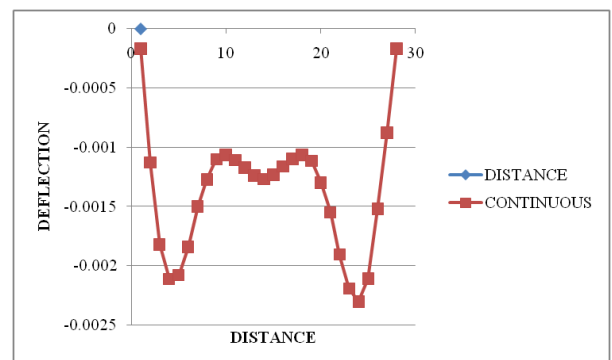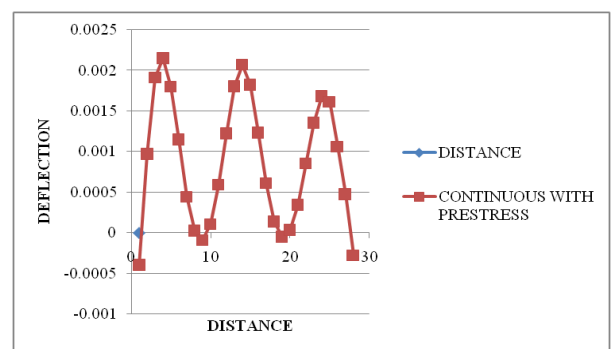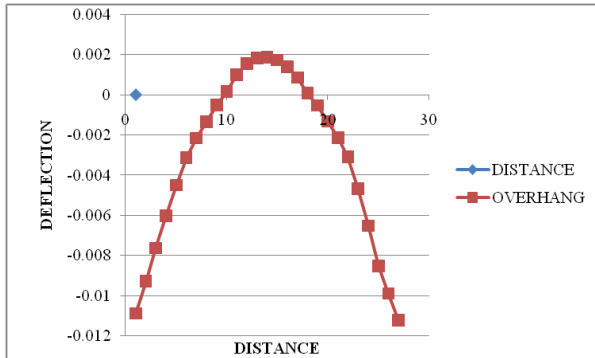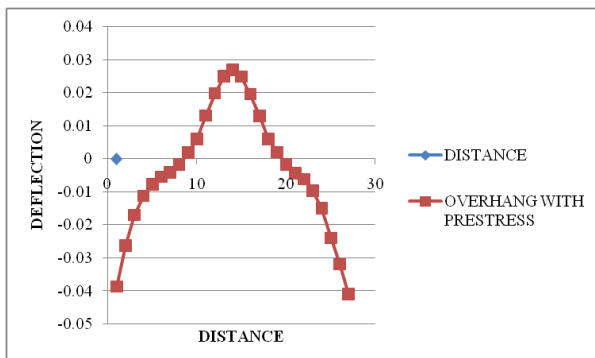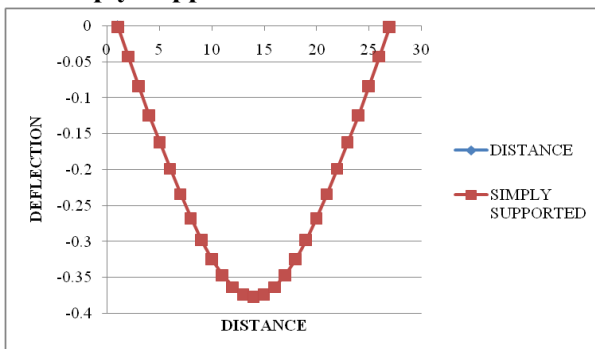**Chart 3.8 -** Deflection Vs Distance for Overhang bridge without Pre-stressing force for 60m span.

Chart 3.9- Deflection Vs Distance for Overhang bridge with Pre-stressing force for 60m span.

5.6 SPAN – 66m
5.6.1 Simply Supported

Chart 4.0 - Deflection Vs Distance for Simply supported bridge without Pre-stressing force for 66m span.

Chart 4.1- Deflection Vs Distance for Simply supported bridge with Pre-stressing force for 66m span.

5.6.2 Continuous

Chart 4.2 - Deflection Vs Distance for Continuous bridge without Pre-stressing force for 66m span.

Chart 4.3 - Deflection Vs Distance for Continuous bridge with Pre-stressing force for 66m span.

5.6.3 Overhang

Chart 4.4- Deflection Vs Distance for Overhang bridge without Pre-stressing force for 66m span.

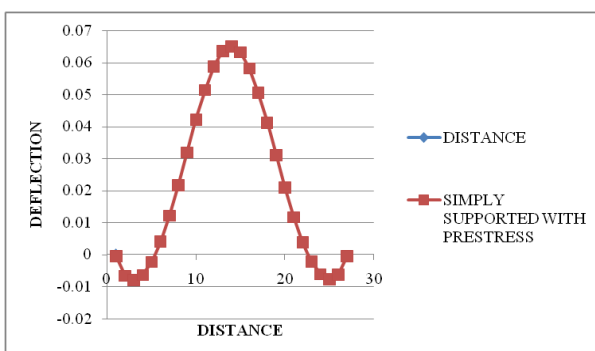**Chart 4.5 -** Deflection Vs Distance for Overhang bridge with Pre-stressing force for 66m span.
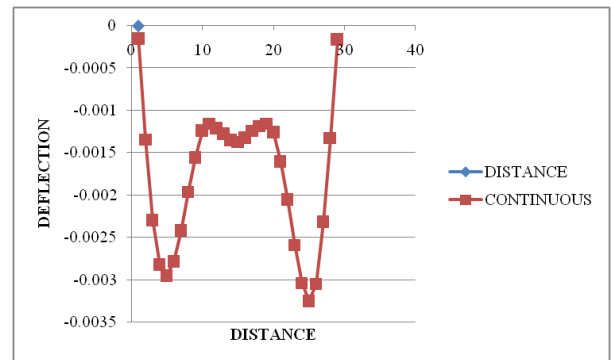
5.7 SPAN – 75m
5.7.1 Simply Supported

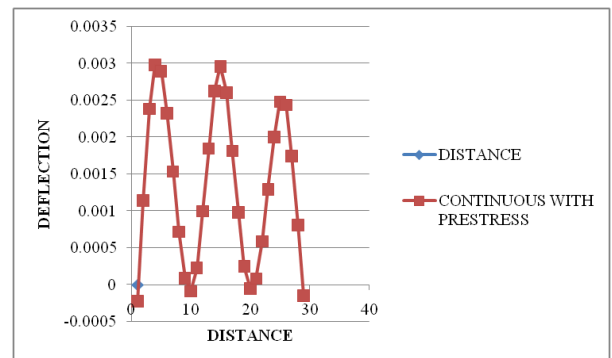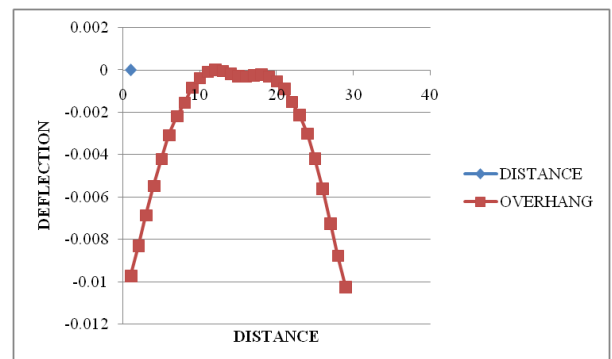**Chart 4.6 -** Deflection Vs Distance for Simply supported bridge without Pre-stressing force for 75m span.

Chart 4.7 - Deflection Vs Distance for Simply supported bridge with Pre-stressing force for 75m span.

5.7.2 Continuous

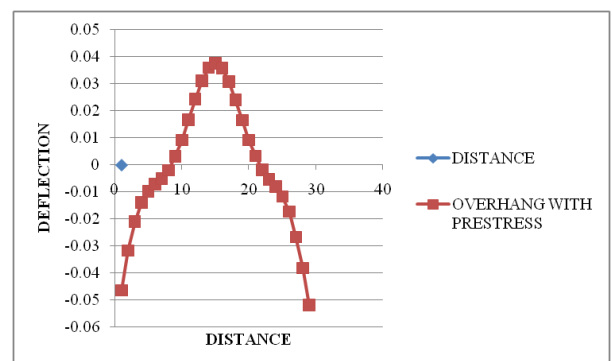**Chart 4.8 -** Deflection Vs Distance for Continuous bridge without Pre-stressing force for 75m span.

Chart 4.9 - Deflection Vs Distance for Continuous bridge with Pre-stressing force for 75m span.
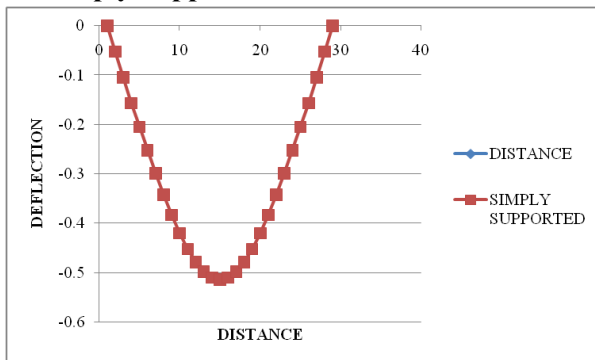
5.7.3 Overhang

Chart 5.0 - Deflection Vs Distance for Overhang bridge without Pre-stressing force for 75m span.
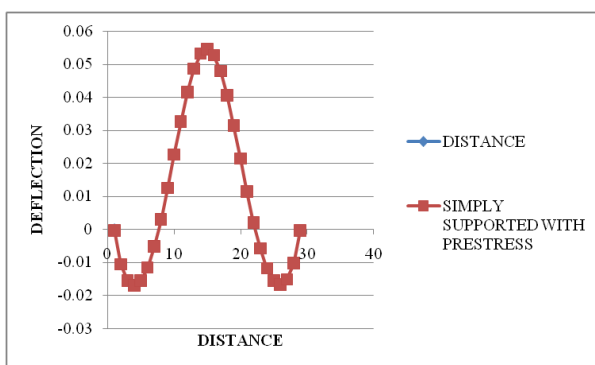

Chart 5.1 - Deflection Vs Distance for Overhang bridge with Pre-stressing force for 75m span.

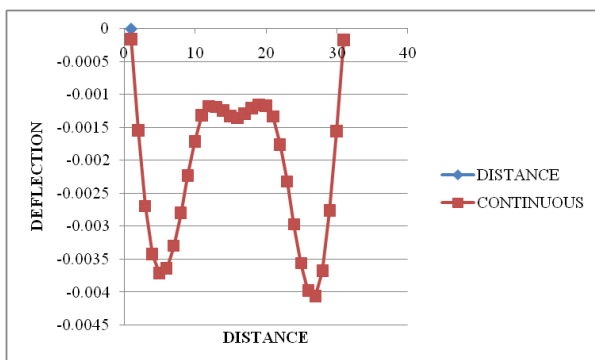## 5.8 SPAN – 81m
5.8.1 Simply Supported

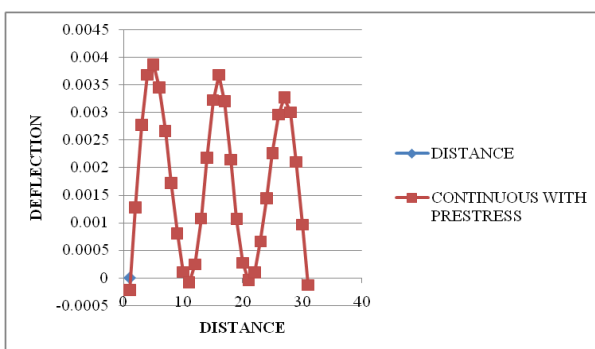**Chart 5.2 -** Deflection Vs Distance for Simply supported bridge without Pre-stressing force for 81m span.

Chart 5.3 - Deflection Vs Distance for Simply supported bridge with Pre-stressing force for 81m span.
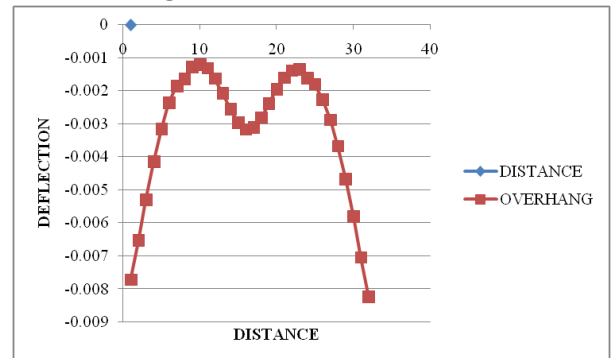
5.8.2 Continuous

Chart 5.4 - Deflection Vs Distance for Continuous bridge without Pre-stressing force for 81m span.
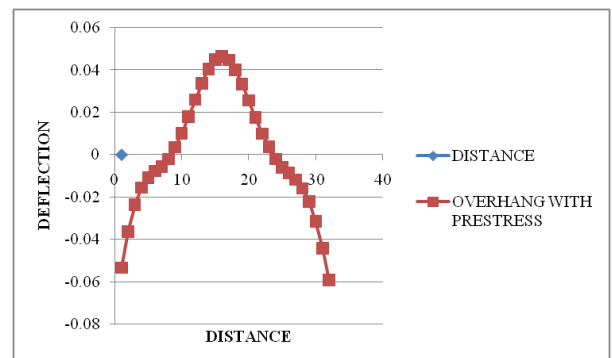

Chart 5.5 - Deflection Vs Distance for Continuous bridge with Pre-stressing force for 81m span.
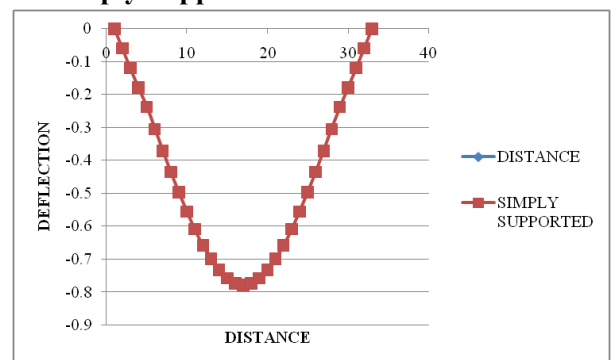
5.8.3 Overhang

Chart 5.6 - Deflection Vs Distance for Overhang bridge without Pre-stressing force for 81m span.
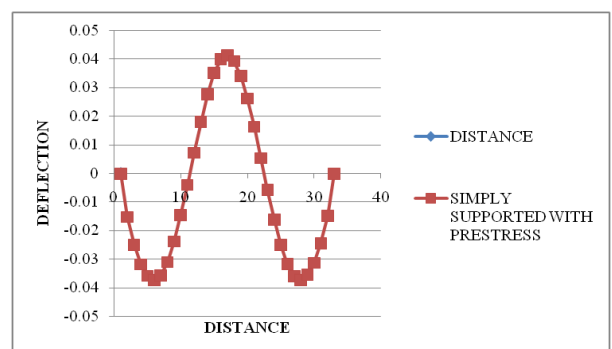

Chart 5.7 - Deflection Vs Distance for Overhang bridge with Pre-stressing force for 81m span.
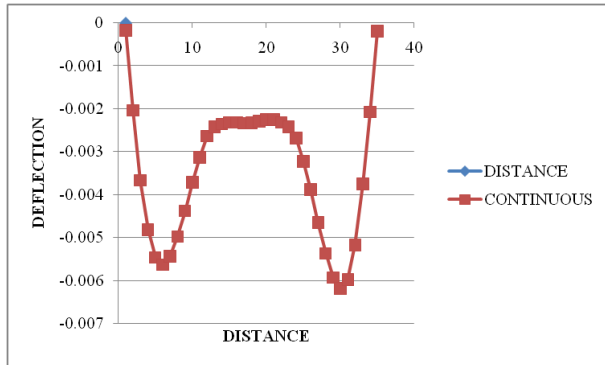
5.9 SPAN – 90m
5.9.1 Simply Supported

Chart 5.8 - Deflection Vs Distance for Simply supported bridge without Pre-stressing force for 90m span.
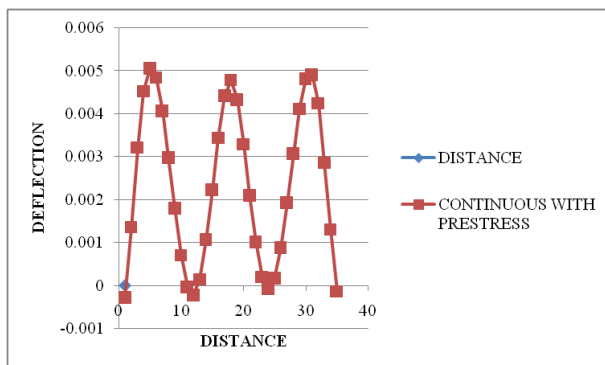

Chart 5.9 - Deflection Vs Distance for Simply supported bridge with Pre-stressing force for 90m span.
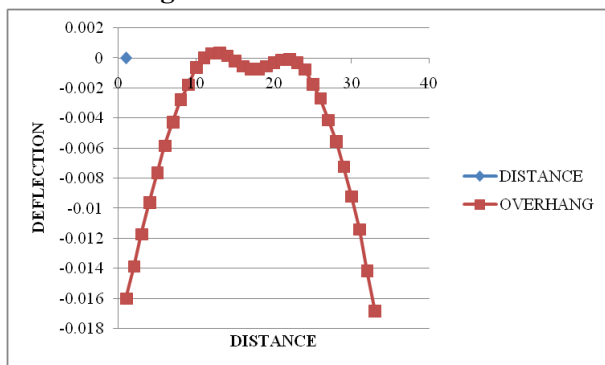
5.9.2 Continuous

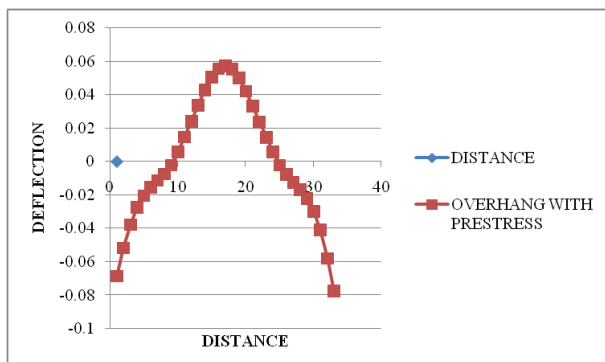**Chart 6.0 -** Deflection Vs Distance for Continuous bridge without Pre-stressing force for 90m span.

Chart 6.1 - Deflection Vs Distance for Continuous bridge with Pre-stressing force for 90m span.
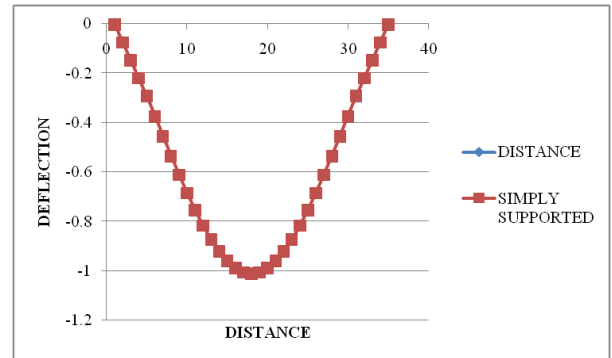
5.9.3 Overhang

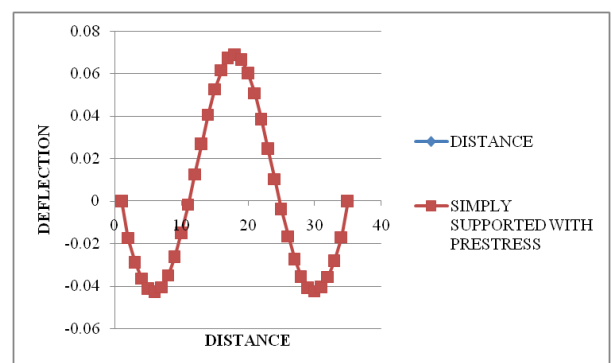**Chart 6.2 -** Deflection Vs Distance for Overhang bridge without Pre-stressing force for 90m span.

Chart 6.3 - Deflection Vs Distance for Overhang bridge with Pre-stressing force for 90m span.
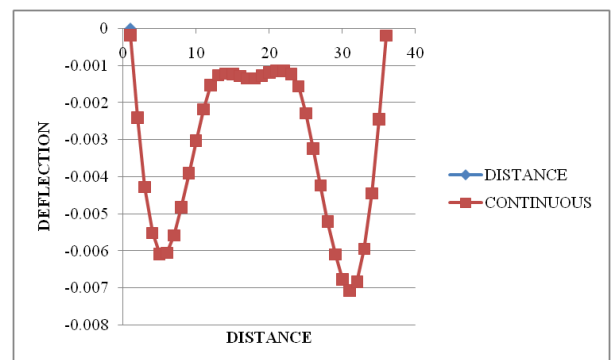
5.10 SPAN – 96m
5.10.1 Simply Supported

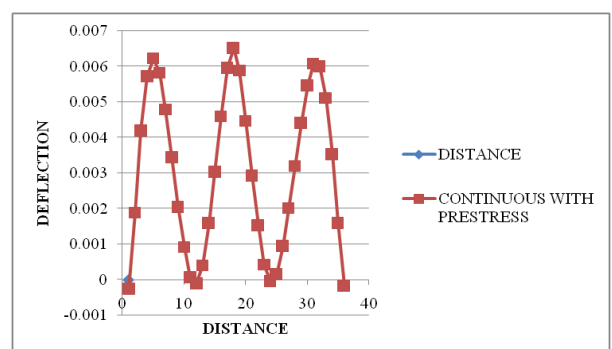**Chart 6.4 -** Deflection Vs Distance for Simply supported bridge without Pre-stressing force for 96m span.

Chart 6.5 - Deflection Vs Distance for Simply supported bridge with Pre-stressing force for 96m span.

5.10.2 Continuous
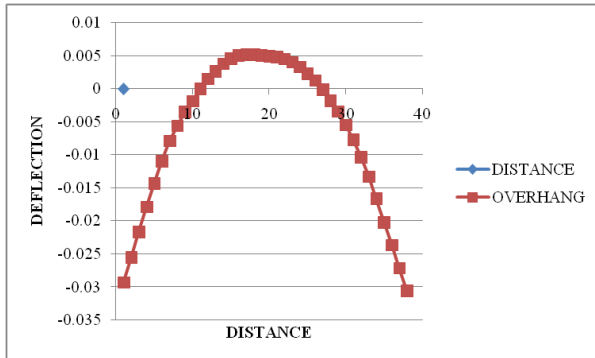

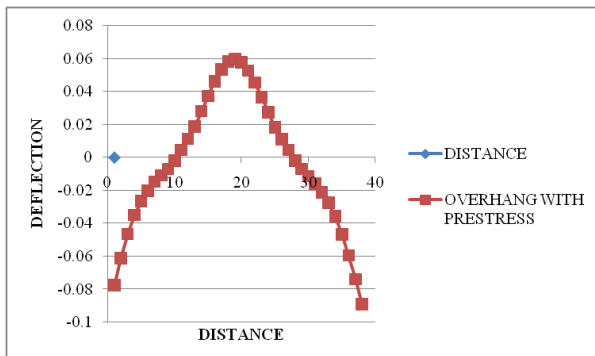**Chart 6.6 -** Deflection Vs Distance for Continuous bridge without Pre-stressing force for 96m span.

Chart 6.7 - Deflection Vs Distance for Continuous bridge with Pre-stressing force for 96m span.
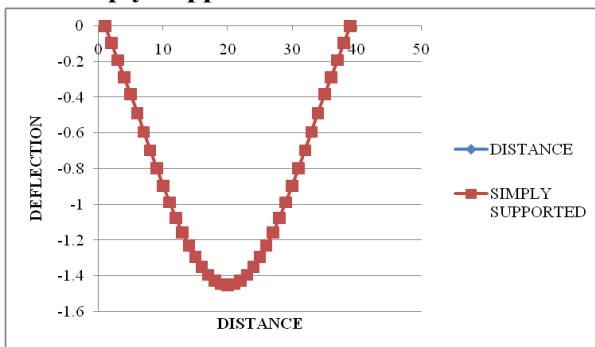
5.10.3 Overhang

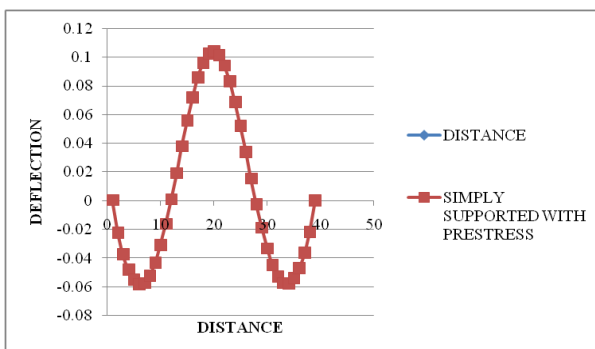**Chart 6.8 -** Deflection Vs Distance for Overhang bridge without Pre-stressing force for 96m span.

Chart 6.9 - Deflection Vs Distance for Overhang bridge with Pre-stressing force for 96m span.
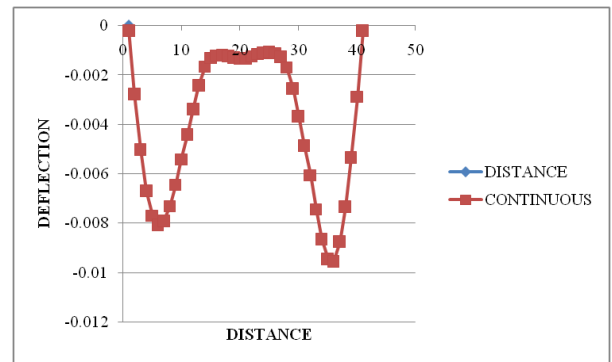
5.11 SPAN – 105m
5.11.1 Simply Supported

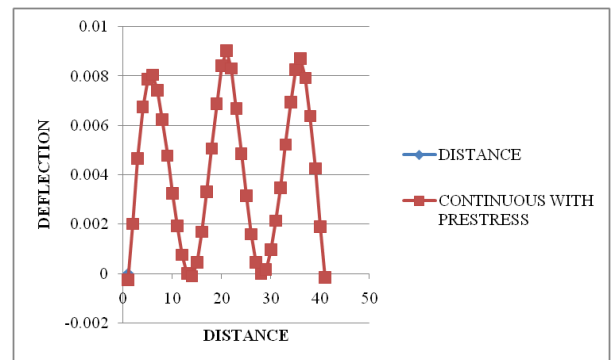**Chart 7.0 -** Deflection Vs Distance for Simply supported bridge without Pre-stressing force for 105m span.

Chart 7.1 - Deflection Vs Distance for Simply supported bridge with Pre-stressing force for 105m span.
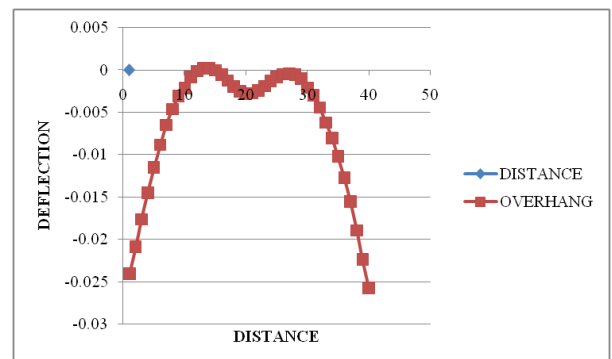
5.11.2 Continuous

Chart 7.2 - Deflection Vs Distance for Continuous bridge without Pre-stressing force for 105m span.
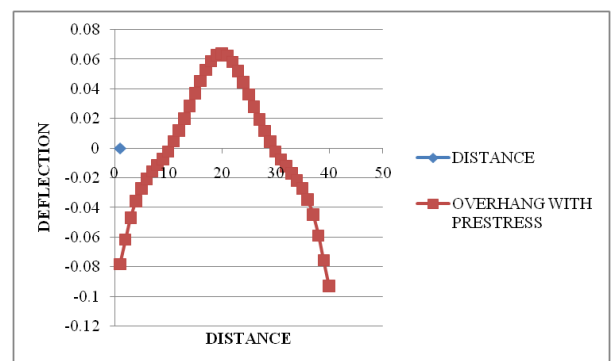

Chart 7.3 - Deflection Vs Distance for Continuous bridge with Pre-stressing force for 105m span.
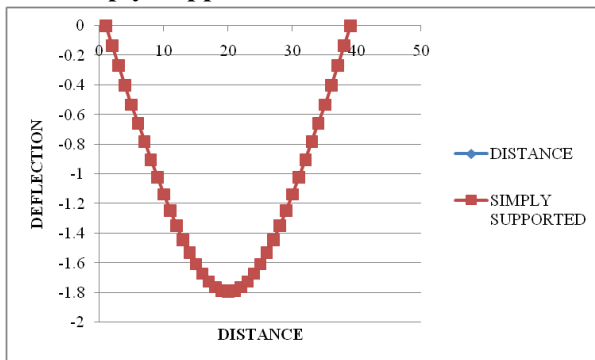
5.11.3 Overhang

Chart 7.4 - Deflection Vs Distance for Overhang bridge without Pre-stressing force for 105m span.
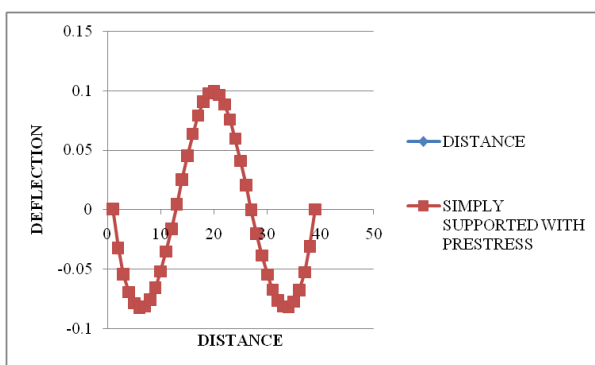

Chart 7.5 - Deflection Vs Distance for Overhang bridge with Pre-stressing force for 105m span.
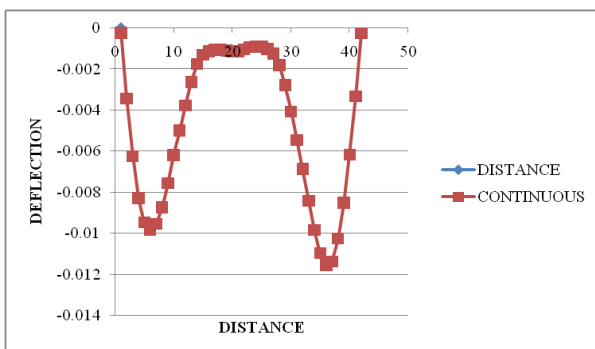
5.12 SPAN – 111m

5.12.1 Simply Supported

Chart 7.6 - Deflection Vs Distance for Simply supported bridge without Pre-stressing force for 111m span.
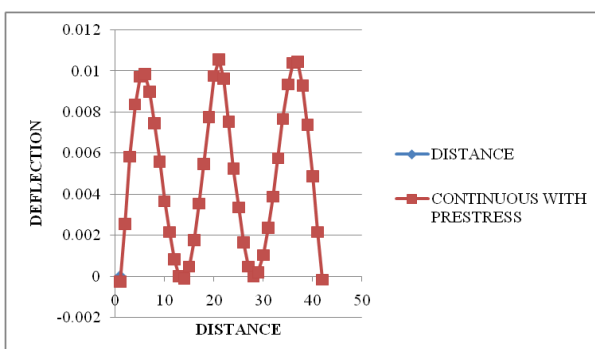

Chart 7.7 - Deflection Vs Distance for Simply supported bridge with Pre-stressing force for 111m span.
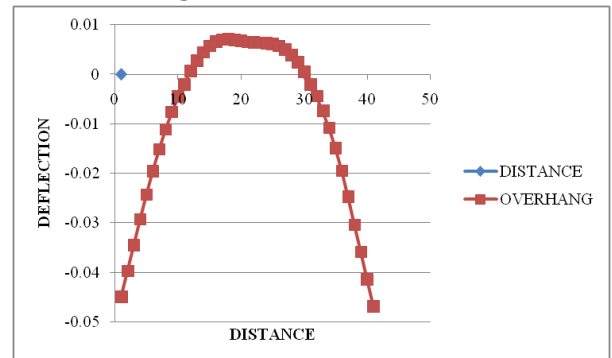
5.12.2 Continuous

Chart 7.8 - Deflection Vs Distance for Continuous bridge without Pre-stressing force for 111m span.
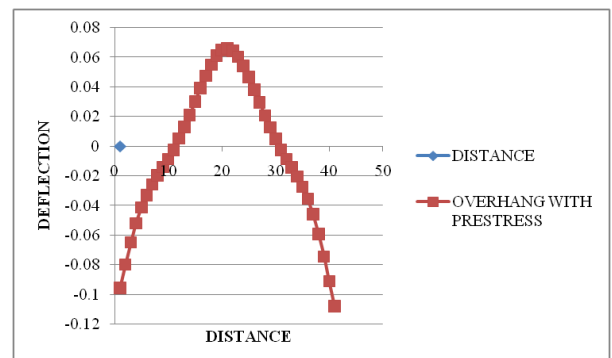

Chart 7.9 - Deflection Vs Distance for Continuous bridge with Pre-stressing force for 111m span.
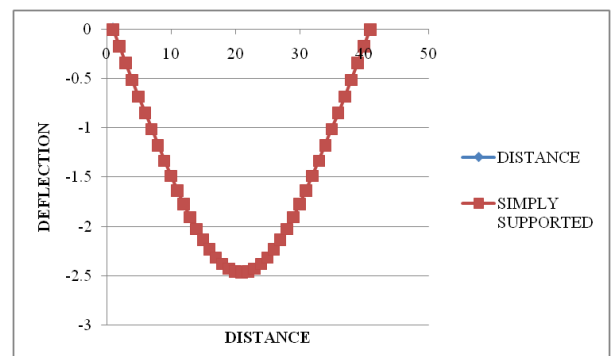
5.12.3 Overhang

Chart 8.0 - Deflection Vs Distance for Overhang bridge without Pre-stressing force for 111m span.
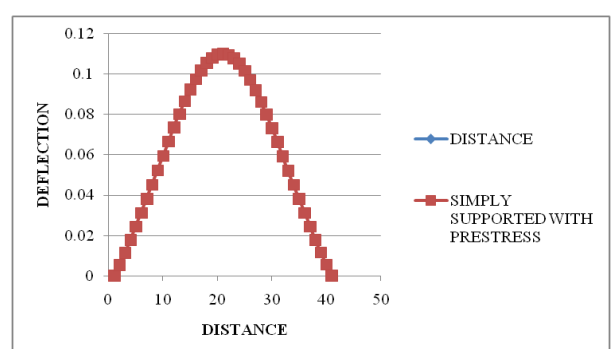

Chart 8.1 - Deflection Vs Distance for Overhang bridge with Pre-stressing force for 111m span.

5.13 SPAN – 120m

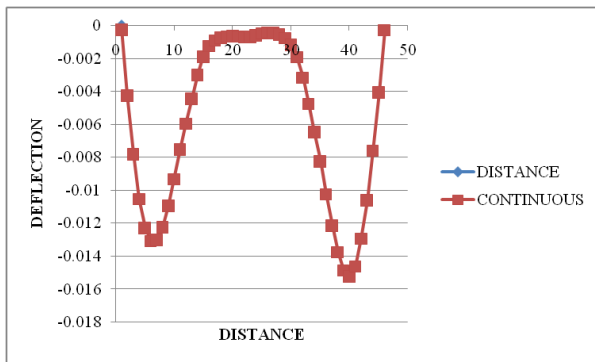### 5.13.1 Simply Supported

Chart 8.2 - Deflection Vs Distance for Simply supported bridge without Pre-stressing force for 120m span.
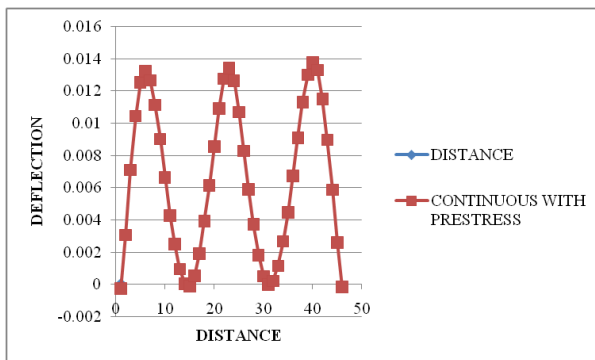

Chart 8.3 - Deflection Vs Distance for Simply supported bridge with Pre-stressing force for 120m span.
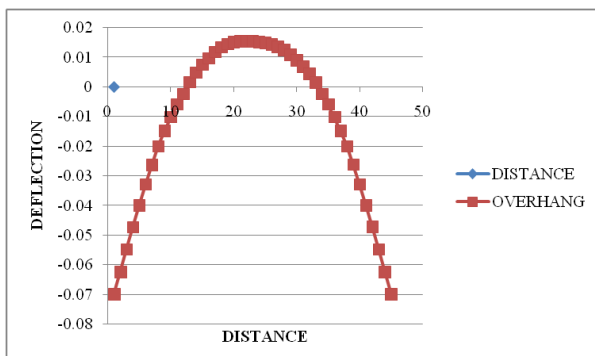
5.13.2 Continuous

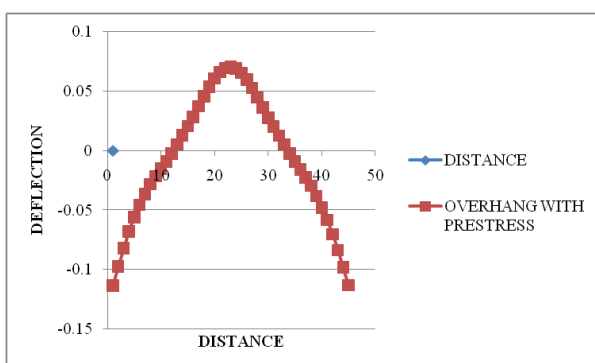**Chart 8.4 -** Deflection Vs Distance for Continuous bridge without Pre-stressing force for 120m span.

Chart 8.5 - Deflection Vs Distance for Continuous bridge with Pre-stressing force for 120m span.
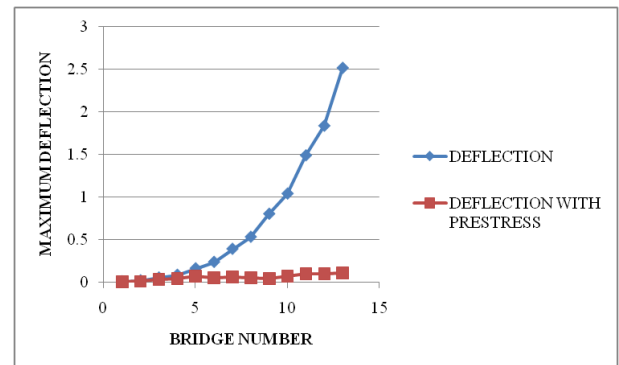
5.13.3 Overhang

Chart 8.6 - Deflection Vs Distance for Overhang bridge without Pre-stressing force for 120m span.

Chart 8.7 - Deflection Vs Distance for Overhang bridge with Pre-stressing force for 120m span.
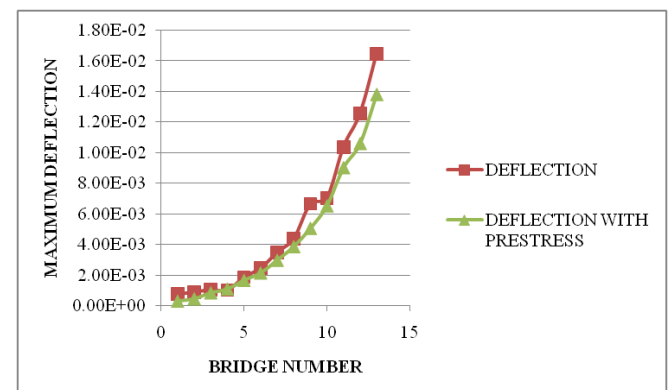
5.14 Maximum Deflection for Simply Supported Bridges

Chart 8.8 - Maximum Deflection Vs Bridge number for Simply supported bridges with and without Pre-stressing force.

Table 1.1 - Maximum Deflection for Simply supported bridges

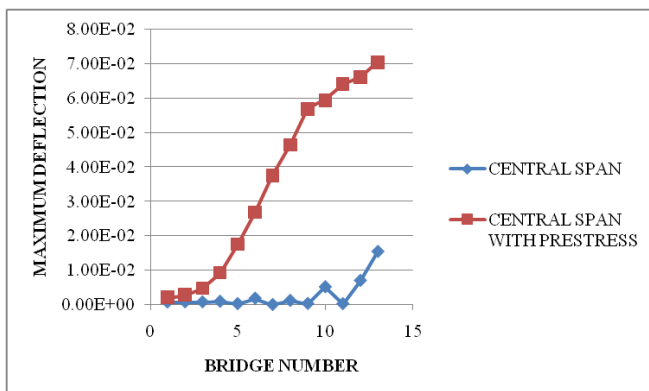| Bridge No.	Span (m)	Deflection without pre-stress (m)	Deflection with Pre-stress (m)	Permiss-ible Deflection according to IS112: 2011 (m)	Pre-stressing force applied (kN)
1	30	-0.0122	0.00738	0.0375	20566
2	36	-0.0235	0.0126	0.045	28900
3	45	-0.0562	0.0343	0.05625	48699
4	51	-0.0881	0.0465	0.06375	60313
5	60	-0.1644	0.0722	0.075	79215
6	66	-0.2393	0.0503	0.0825	80000
7	75	-0.3925	0.0651	0.09375	100000
8	81	-0.5328	0.0546	0.10125	110000
9	90	-0.8031	0.048	0.1125	130000
10	96	-1.0392	0.069	0.12	150000
11	105	-1.487	0.104	0.13125	180000
12	111	-1.8335	0.0997	0.13875	200000
13	120	-2.51	0.11	0.15	10000

5.15 Maximum Deflection For Continuous Bridges

Chart 8.9 - Maximum Deflection Vs Bridge number for Continuous bridges with and without Pre-stressing force.
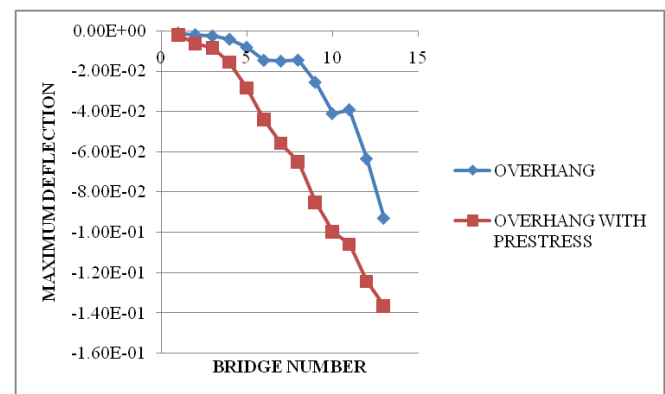
Table 1.2 - Maximum Deflection for Continuous bridges

Bridge No.	Span(m)	Deflection without pre-stress (m)	Deflection With pre-stress (m)	Permiss-ible Deflection according to IS112: 2011 (m)	Pre-stressing Force applied(kN)
1	30	7.75E-04	3.11E-04	0.0125	2585.853
2	36	9.03E-04	4.61E-04	0.015	3308.077
3	45	1.06E-03	8.52E-04	0.01875	4518.352
4	51	1.03E-03	1.10E-03	0.02125	5228.439
5	60	1.89E-03	1.67E-03	0.025	6663.56
6	66	2.47E-03	2.15E-03	0.0275	7647.746
7	75	3.51E-03	2.98E-03	0.03125	9270.538
8	81	4.41E-03	3.87E-03	0.03375	10570.54
9	90	6.68E-03	5.06E-03	0.0375	12606.186
10	96	7.07E-03	6.53E-03	0.04	14460.382
11	105	0.0104	9.02E-03	0.04375	17208.913
12	111	0.0126	0.0106	0.04625	18964.575
13	120	0.0165	0.0138	0.05	21735.196

5.16 Maximum Deflection For Overhang Bridges

Chart 9.0 - Maximum Deflection Vs Bridge number for Overhang bridges (central span) with and without Pre-stressing force.

Chart 9.1 - Maximum Deflection Vs Bridge number for Overhang bridges with and without Pre-stressing force.

Table 1.3 - Maximum Deflection for Overhang bridges

Bridge No.	Span (m)	Deflec-tion with Out pre-stress (b/w support) (m)	Deflec-tion with pre-stress (b/w support) (m)	Deflec-tion with Out pre-stress (over hang) (m)	Deflec-tion with pre-stress (over hang) (m)	Permissible deflection according to IS112:2011 (m) B/w support	Over hang	Pre-stressing force applied (kN)
1	30	-7.50E-04	2.05E-03	-1.09E-03	-2.22E-03	0.02	0.02	7097
2	36	-8.00E-04	2.81E-03	-1.89E-03	-6.50E-03	0.0225	0.03	10294
3	45	-7.83E-04	4.70E-03	-2.55E-03	-8.75E-03	0.03	0.04	13392
4	51	-9.53E-04	9.31E-03	-4.15E-03	-1.58E-02	0.0325	0.04	18255
5	60	-2.87E-04	0.0176	-8.13E-03	-0.0285	0.0375	0.05	25473
6	66	1.86E-03	2.69E-02	-0.0146	-0.0441	0.04	0.06	31852
7	75	1.39E-05	0.0376	-0.015	-0.0559	0.0475	0.06	37123
8	81	-1.20E-03	0.0465	-0.0145	-0.0651	0.0525	0.07	40722
9	90	3.25E-04	5.70E-02	-0.0255	-0.0852	0.0575	0.07	41000
10	96	5.19E-03	0.0595	-0.041	-0.0996	0.06	0.08	36000
11	105	2.61E-04	0.0642	-0.0391	-0.1059	0.0675	0.09	36000
12	111	7.04E-03	6.62E-02	-0.0634	-0.1243	0.07	0.09	30000
13	120	-0.0155	0.0706	-0.0929	-0.1365	0.075	0.1	25000

6. CONCLUSION

- The Deflection diagram gets inverted after the application of pre-stressing force for Simply Supported and Continuous bridges, whereas it remains the same for Overhang bridges.

- As span increases, there is a major lowering in the deflection after pre-stressing for Simply supported bridges.

- As span increases, there is a slight lowering in the deflection after pre-stressing for Continuous bridges.

- For Overhang bridges, the deflection is maximum when subjected to Pre-stressing.

- After the application of Pre-stressing force, the deflection values reduce gradually for Simply Supported, Continuous and Overhang Bridges respectively.

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BIOGRAPHIES

Rashmi R Koushik, MTech Student, Department of Civil Engineering, Global Academy of Technology, Bengaluru - 560098

Shilpa Patil, Asst. Professor, Department of Civil Engineering, Global Academy of Technology, Bengaluru -560098

Rakesh R, MTech Student, Department of Civil Engineering, Global Academy of Technology, Bengaluru -560098