ANALYSIS OF PRESTRESSED CONCRETE GIRDER FOR BRIDGES

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***Abstract**: Bridge construction today has achieved a worldwide level of importance. Bridges are the key elements in any road network and use of pre-stress girder type bridges gaining popularity in bridge engineering fraternity because of its better stability, serviceability, economy, durability, aesthetic appearance and structural efficiency. Normally the type of construction used is reinforced concrete construction, steel construction or steel composite construction. When the span is high reinforced concrete construction is uneconomical due to increase in depth of span. Prestressed member, which are free from tensile stress under working loads, the cross section is more efficiently utilized than reinforced concrete section. Prestressed concrete is used for long span bridges above span length of 10m. Conventionally in Bridge analysis, the Super-structure and Substructure are analyzed separately. The Super-structure is usually a grid consisting of main girders, transverse diaphragms and deck slab. The deck slab is discretized into a grid of line elements. The supports of the main girders are pinned. The super-structure is analyzed for un-factored Gravity loads and Moving vehicular loads as per IRC: 6-2014 and as per IRC: 18-2000. The work discusses about the modelling and analysis pattern of prestressed concrete bridges for different tendon profiles in MIDAS CIVIL software. The curved profile gives reduction in stress level and also deflection compared to straight tendon profile.*

***Keywords**: Prestressed concrete girder, post tensioning, moving load analysis, tendons, tendon profile.*

1. INTRODUCTION

A bridge is a structure built to span a physical obstacle, such as a body of water, valley, or road, without closing the way underneath. It is constructed for the purpose of providing passage over the obstacle, usually something that can be detrimental to cross otherwise. There are many different designs that each serve a particular purpose and apply to different situations. Designs of bridges vary depending on the function of the bridge, the nature of the terrain where the bridge is constructed and anchored, the material used to make it, and the funds available to build it. Prestressed concrete is a form of concrete used in construction. It is substantially "prestressed" (compressed) during its fabrication, in a manner that strengthens it against tensile forces which will exist when in service. Prestressed concrete is used in a wide range of building and civil structures where its improved performance can allow for longer spans, reduced structural thicknesses, and material savings compared with simple reinforced concrete. Typical applications include high-rise buildings, residential slabs, foundation systems, bridge and dam structures, silos and tanks, industrial pavements and nuclear containment structures. Concrete is the most popular structural material for bridges, and prestressed concrete is frequently adopted. There are many types of bridges. Some of them are, Short span bridge, Medium span bridge, Long span bridge and Cable suspension bridge.

In short-span bridges of around 10 to 40 meters (30 to 130 ft.), Prestressing is commonly employed in the form of precast pre-tensioned girders or planks. Medium- length structures of around 40 to 200 meters (150 to 650 ft.), typically use precast- segmental, in-situ balanced-cantilever and incrementally-launched designs. For the longest bridges, prestressed concrete deck structures often form an integral part of cable-stayed designs.

1.1 MIDAS CIVIL

Midas civil is the state of art engineering software that set a new standard for the design of bridges and civil structures. It features a distinctively user friendly interface and optimal design solution functions that can account for construction stages and time dependent properties. It's a highly developed modelling and analysis function enable engineers to overcome common challenges and inefficiencies of finite element analysis. With Midas civil, you will be able to create high quality designs with unprecedented levels of efficiency and accuracy.

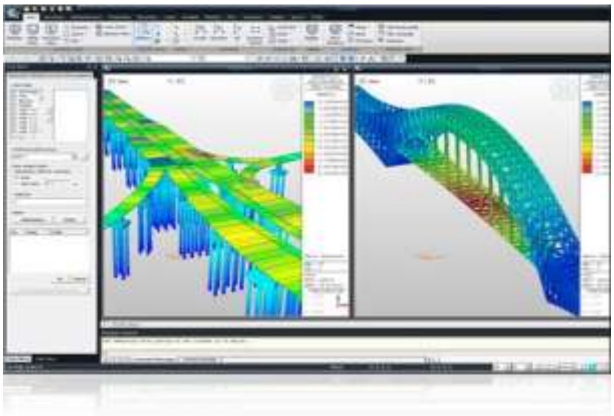


Figure 1.1 Analysis in MIDAS

The post-processor can automatically create load combinations in accordance with specified design standards. Changing the type of display can produce various forms of graphic output. Practically all the results can be animated, namely, mode shapes, time history results of displacements and member forces, dynamic analysis results and static analysis results. Midas Civil also provides results that are compatible with MS Excel, which enables the user to review all analysis and design results systematically. Midas Civil provides various design check and load rating features including: Euro code & AASHTO LRFD Bending, shear & torsional strengths Composite plate girder design Member forces & stresses for each construction stage and max & min stress summations Automatic generation of load combinations in accordance with various design codes MS Excel format calculation report.

1.2 OBJECTIVE

1. Analysis of prestressed concrete girder using MIDAS CIVIL software.
2. Comparative study between straight and parabolic cable profile.
3. To investigate the effect of eccentricity, prestressing force and Cable profile and to determine the structural static properties such as deflections and stress distributions.

2. CODES AND STANDARDS

2.1 LOADS

The loads are based on IRC: 6-2014 standard specifications and code of practice for road bridges (section: II) loads and stresses.

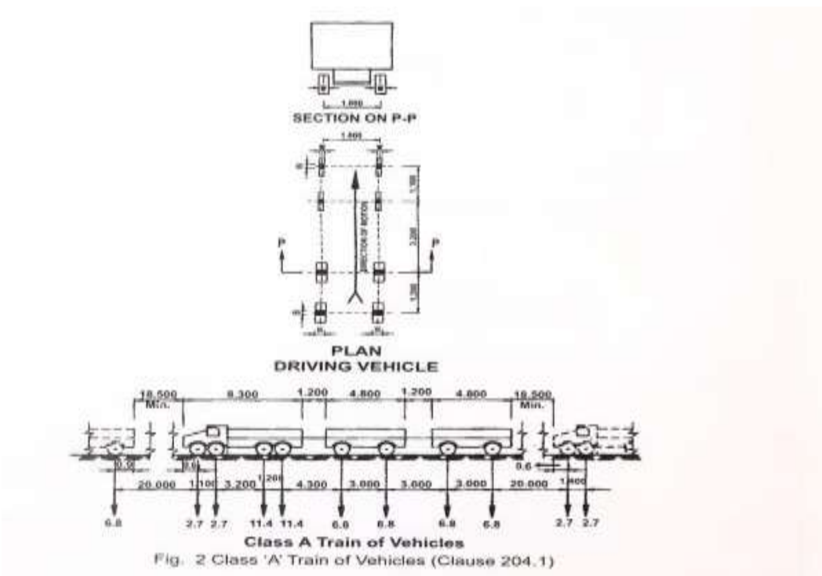


Figure 2.1 Loading standard for IRC class A loading

2.2 Design procedure for Box girders as per IRC: 18-2000

2.2.1Web thickness

The thickness of the web shall not be less than d/36 plus twice the clear cover to the reinforcement plus diameter of the duct hole where'd' is the overall depth of the box girder measured from the top of the deck slab to the bottom of the soffit or 200 mm plus the diameter of duct holes, whichever is greater. Where cables cross within the web, suitable increase in the thickness over the above shall be made. In case of cast in situ cantilever construction, if the prestressing cables are anchored in the web, the web shall be locally thickened to not less than 350 mm nor less than that recommended by the prestressing system manufacturer, subject to design requirements.

2.2.2 Bottom flange thickness

The thickness of the bottom flange of box girder shall be not less than 1/20th of the clear web spacing at the junction with bottom flange or 200 mm whichever is more.

2.2.3 Top flange thickness

The minimum thickness of the deck slab including that at cantilever tips shall be 200 mm .For top and bottom flange having prestressing cables, the thickness of such flange shall not be less than - 150 mm plus diameter of duct hole.

2.2.4 Spacing

In box girders, effective and adequate bond and shear resistance shall be provided at the junction of the web and the slabs. The slabs may be considered as an integral part of the girder and the entire width may be assumed to be effective in compression. For very short spans or where web spacing is excessive or where overhangs are excessive, analytical investigation shall be made to determine the effective flange width.

2.2.5 Thermal effects

For cantilever construction, preference shall be given to box type cross section with diaphragms provided at supports. Sudden change in depth of superstructure should not be permitted. For reducing the thermal effect suitable ventilation should be provided in box sections.

2.2.6 Ultimate strength

A prestressed concrete structure and its constituent members shall be checked for failure conditions at an ultimate load of 1.25 G+2SG+ 2.5 Q under moderate condition and 1.5 G +2 SG + 2.5 Q under severe exposure conditions where G, SG and Q denote permanent load, superimposed dead load and live load including impact respectively. The superimposed dead load shall include dead load of precast footpath, hand rails, wearing course, utility services, kerbs etc. For sections, where the dead load causes effects opposite to those of live load, the sections shall also be checked for adequacy for a load of G+ SG+2.5Q.

2.2.6 Calculation of ultimate strength

Under ultimate load conditions, the failure may either occur by yielding of the steel (under-reinforced section) or by direct crushing of the concrete (over-reinforced section). Non-prestressed reinforcement may be considered as contributing to the available tension for calculation of the ultimate moment of resistance in an amount equal to its area times its yield stress, provided such reinforcement is welded or has sufficient bond under conditions of ultimate load. Ultimate moment of resistance of sections, under these two alternative conditions of failure shall be calculated by the following formulae and the smaller of the two values shall be taken as the ultimate moment of resistance for design:

Failure by yield of steel (under-reinforced section)

$M_{ult} = 0.9\, d_b\, A_s\, f_p$

A_s = the area of high tensile steel

f_p = the ultimate tensile strength for steel without definite yield point

d_b = the depth of the beam from the maximum compression edge to the centre of gravity of the steel tendons.

Failure by crushing of concrete

For rectangular section, $M_{ult} = 0.176\ b\ d_b^2\ f_{ck}$

For Tee sections,

M_{ult} = ($0.176 b_w\ d^2\ f_{ck}$ + 0.67□.8 (b $_w$) (d-0.5D_f) $D_f\ f_{ck}$) .

B = the width of rectangular section or web of a Tee 0.8beam.

B_f = the width of flange of Tee beam.

t =thickness of flange of Tee beam.

2.2.7 Shear

Sections uncracked in flexure

The ultimate shear resistance of a section uncracked in flexure, V., corresponds to the occurrence of a maximum principal tensile stress, at the centroidal axis of the section, of ft= 0.24 fck.

$V_{co} = 0.67bd\sqrt{(f_t^2+0.8f_{cp}f_t)}$

b = width in the case of rectangular member and width of the rib in the case of T, I and L beams.

d= overall depth of the member.

f_t=maximum principal tensile stress given by 0.24.

f_{cp} = compressive stress at centroidal axis due to prestress taken as positive.

Sections cracked in flexure:

The ultimate shear resistance of a section cracked in flexure, V_{er} may be calculated using the equation given below.

$V_{cr} = 0.037bd_b\sqrt{f_{ck}} + (M_t/M)\ V$

Where d, = is the distance from the extreme compression fiber to the centroid of the tendons at the section considered;

M = is the cracking moment at the section considered,

$M_t = (0.37\sqrt{f_{ck}} + 0.8\ f_{pt})I/y$ in which f, is the stress due to prestress only at the tensile fiber distance y from the centroid of the concrete section which has a second moment of area I;

V and M = are the shear force and corresponding bending moment V_{cr} = should be taken as not less than 0.1 bd $\sqrt{f_{ck}}$ The value of V, calculated at a particular section may be assumed to be constant for a distance equal to d,/2, measured in the direction of increasing moment from that particular section

2.2.8 Minimum reinforcement

The quantity of untensioned steel required for design or constructional purposes shall not be less than the minimum stipulated in Clauses 15.2 to 15.4. Various types of minimum steel requirements need not be added together. Bars in such reinforcement shall, however, not be placed more than 200 mm apart. The minimum diameter shall not be less than 10 mm for severe condition of exposure and 8 mm for moderate condition of exposure.In case of in-situ segmental construction for bridges located in marine environment continuity of untensioned reinforcement from one segment to the next shall be ensured.

In the vertical direction, a minimum reinforcement shall be provided in the bulb/web of the beams/rib of box girders, such reinforcement being not less than 0.3 per cent of the cross sectional area of the bulb/web in plan for mild steel and 0.18 per cent for HYSD bars respectively. Such reinforcement shall be as far as possible uniformly spaced along the length of the web. In the bulb portion, the cross sectional area of bulb in plan shall be taken. .

In all the corners of the section, these. Reinforcements should pass round a longitudinal bar having a diameter not less than that of the vertical bar or round a group of tendons. For tee- beams, the arrangement in the bulb portion.

Longitudinal reinforcements provided shall not be less than 0.25 per cent and 0.15 per cent of the gross cross sectional area of the section for mild steel and HYSD bars respectively, where the specified grade of concrete is less than M 45. In case the grade of concrete is M 45 or more, the provision shall be increased to 0.3 per cent and 0.18 per cent respectively. Such reinforcement shall as far as possible be evenly spaced on the periphery. Non-prestressed high tensile reinforcement can also be reckoned for the purpose of fulfilling the requirement of this clause.For solid slabs and top and bottom slabs of box girders, the top and underside of the slabs shall be provided with reinforcement consisting of a grid formed by layers of bars. The minimum steel provided shall be as follows:

For solid slabs and top slab of box girders: 0.3 per cent and 0.18 per cent of the gross cross sectional area of the slab for MS and HYSD bars respectively, which shall be equally distributed at top and bottom.

For soffit slab of box girders: The longitudinal steel shall be -at least 0.18 per cent and 0.3 per cent of sectional area for HYSD and MS bars respectively. The minimum transverse reinforcement shall be 0.3 per cent and 0.5 per cent of the sectional area for HYSD and MS bars respectively. The minimum reinforcement shall be equally distributed at top and bottom.

For cantilever slab minimum reinforcement of 4 nos. of 16 mm dia HYSD bars or 6 nos. of 16 mm diameter MS bars should be provided with minimum spacing at the tip divided equally between the top and bottom surface parallel.to support.N.B. Not withstanding the nomenclature “untensioned steel”, this provision of reinforcement may be utilized for withstanding all action affects, if necessary.

2.2.9 End block

End block shall be designed to distribute the concentrated prestressing force at the anchorage. It shall have sufficient area to accommodate anchorages at the jacking end and shall preferably be as wide: as the narrowest flange of the beam. Length of end block in no case shall be less than 600 mm nor less than its width. The portion housing the anchorages shall ‘as far as possible be precast.

The bursting forces in the end blocks, should be assessed on the basis of the ultimate tensile strength. The bursting tensile force, Fbst existing in an individual square end block loaded by a symmetrically placed square anchorage or bearing plate.

Where,

$2\ Y_o$ = is the side of end block;

$2\ Y_{po}$ = is the side of loaded area;

P_k = is the load in the tendon;

F_{bst} = is the bursting tensile force.

3. FOUR-CELL PRESTRESSED BOX GIRDER

3.1 PROBLEM STATEMENT

A box girder for 2 lane national highway bridge, with the data below:-

Type of support: - simply supported

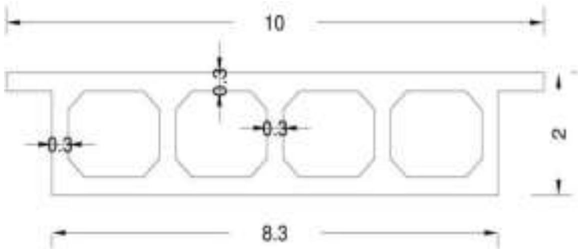
Length: - 30 m

Carriageway width: - 7.5m

Foot path width: - 1.25m

Segmental width: - 10m

Load type: - IRC class A loading and IRC class 70R loading.



Concrete grade: M60

Figure 3.1 Cross section of girder (units in meter)

3.2 MATERIAL PROPERTIES AND ALLOWABLE STRESSES

TENDON PROPERTIES

Pre-stressing Strand: ϕ15.2 mm (0.6”strand)

Yield Strength: f_{py} = 1.56906 X 106 kN/m^2

Ultimate Strength: f_{pu} = 1.86326 X 106 kN/m^2

Cross Sectional area of

each tendon = 0.0037449 m^2

Elastic modulus: E_{ps} = 2 X 108 kN/m^2

Jacking Stress: f_{pj} = 0.7f_{pu} = 1330 N/mm^2

Curvature friction factor: μ= 0.3 /rad

Wobble friction factor: k = 0.0066 /m

3.3 SECTION PROPERTIES

Top slab thickness = 300 mm Bottom Slab thickness = 300 mm External wall thickness = 300 mm Internal Wall thickness = 300 mm Span = 100m

Total width = 10m Road

Width of Carriage way = 7.5m

Wearing coat = 80mm

Cross-sectional Area = 7.58 m^2

I_{XX}= 11.92427m^4

I_{YY}= 4.286286m^4

I_{ZZ} = 53.79855m^4

Center y = 5 m ; Centre z = 1.06 m

3.4 WEB THICKNESS (As per IRC: 18-2000)

The thickness of the web shall not be less than d/36 plus twice the clear cover to the reinforcement plus diameter of the duct hole where‘d’ is the overall depth of the box girder measured from the top of the deck slab to the bottom of the soffit or 200 mm plus the diameter of duct holes, whichever is greater. Where cables cross within the web, suitable increase in the thickness over the above shall be made. In case of cast in situ cantilever construction, if the prestressing cables are anchored in the web, the web shall be locally thickened to not less than 350 mm.

Web thickness = 300 mm > permissible value (safe)

3.5 BOTTOM FLANGE THICKNESS

The thickness of the bottom flange of box girder shall be not less than 1/20th of the clear web spacing at the junction with bottom flange or 200 mm whichever is more.

Bottom flange thickness = 300 mm > permissible value (safe)

3.6 TOP FLANGE THICKNESS

The minimum thickness of the deck slab including that at cantilever tips shall be 200 mm. For top and bottom flange having prestressing cables, the thickness of such flange shall not be less than 150 mm plus diameter of duct hole. Top Flange thickness = 300 mm > permissible value (safe).

Figure 3.2 Model view of girder in MIDAS

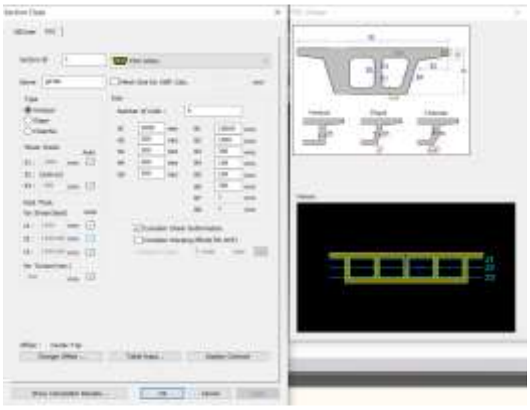


Figure 3.3 Section data given for analysis

3.7 LOADING ON BOX GIRDER

The loads are applied as per IRC: 6-2014 standard specifications and code of practice for road bridges (section: II) loads and stresses. Generally there are many types of loading classes in IRC: 6-2014.The loads applied are IRC CLASS 'A' loading and IRC CLASS '70R' loading as per IRC 6-2014 clause 204.1.

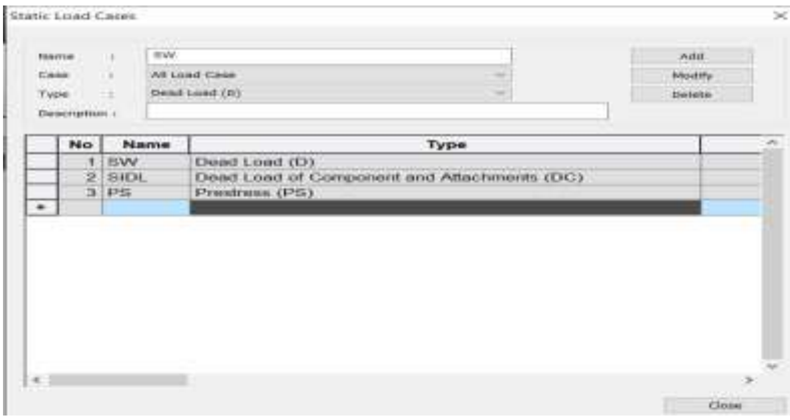


Figure 3.4 Load cases for analysis

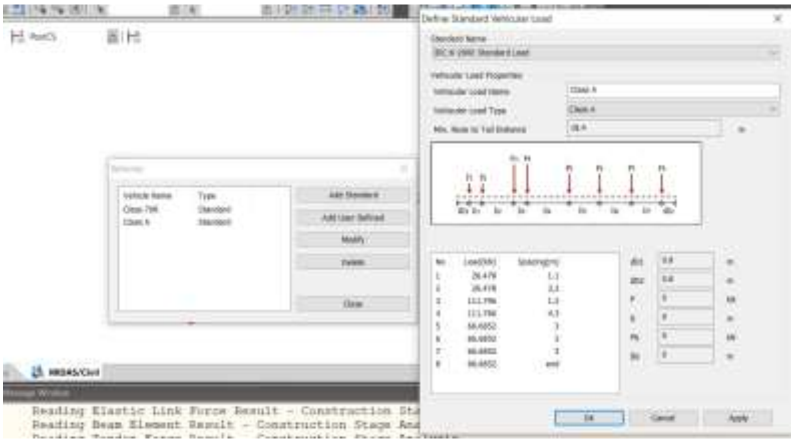


Figure 3.5 Vehicle standards for moving loads

3.8 CHECK FOR MINIMUM SECTION MODULUS (from analysis)

M_{gb}=12927 kNm and M_{qb} =6899 kNm

f_{br} = (ηfct-ftw) = (0.8x20) = 16 N/mm2

$\boldsymbol{Zb} = \boldsymbol{Mq} + (\mathbf{1} - \eta)/\boldsymbol{fbr}$

$Z_b = 0.524\times10^{9}$ mm^3 < 0.94×10^{9} mm^3

Hence the section provided is safe.

3.9 PRESTRESSING FORCE

For two continuous span AB and BC concordant cable profile is selected so that the secondary moments are zero. The cable profile selected is shown in figure 3.6 and 3.7. For straight cable profile the cable is provided at a distance of 0.5m from the top and for the parabolic profile at mid-span 0.35m and at mid-support section 0.7m from the centroid.

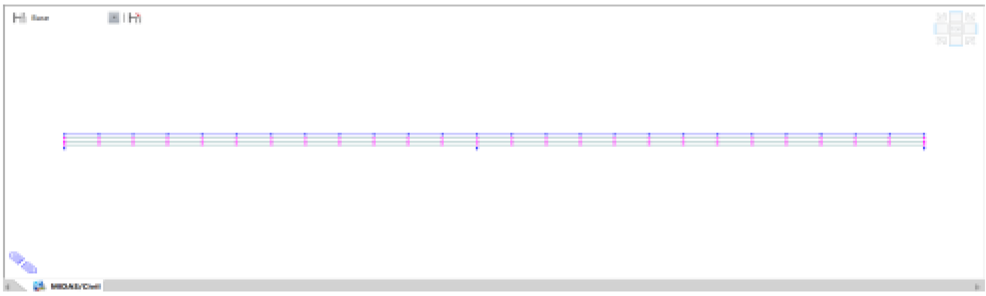


Figure 3.6 Concentric cable profile

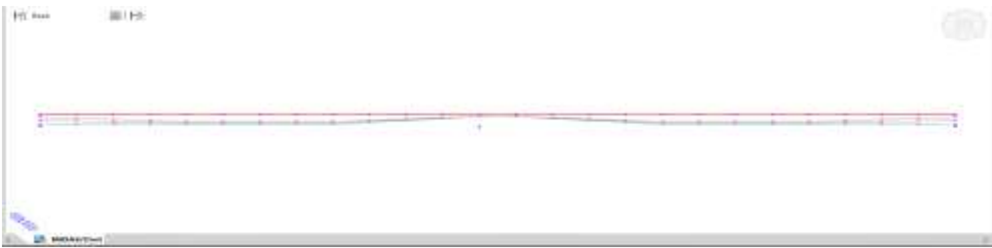


Figure 3.7 Parabolic cable profile

Using Freyssinet system with anchorage type 27K-15(27 strands of 15.2mm diameter) in 110mm diameter ducts.

Force in each cable = $(27\times0.8\times265)$ = 5724 kN

Provide each cables an prestressing force of P = 5000kN

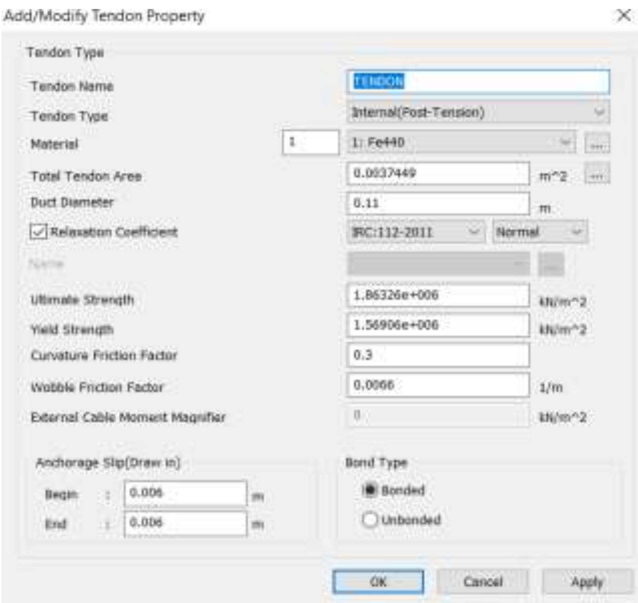


Figure 3.8 Tendon property for straight and parabolic profile

3.10 CALCULATION OF ULTIMATE FLEXURAL STRENGTH (As per IRC: 18-2000)

Centre of span section

Failure by yield of steel (under-reinforced section)

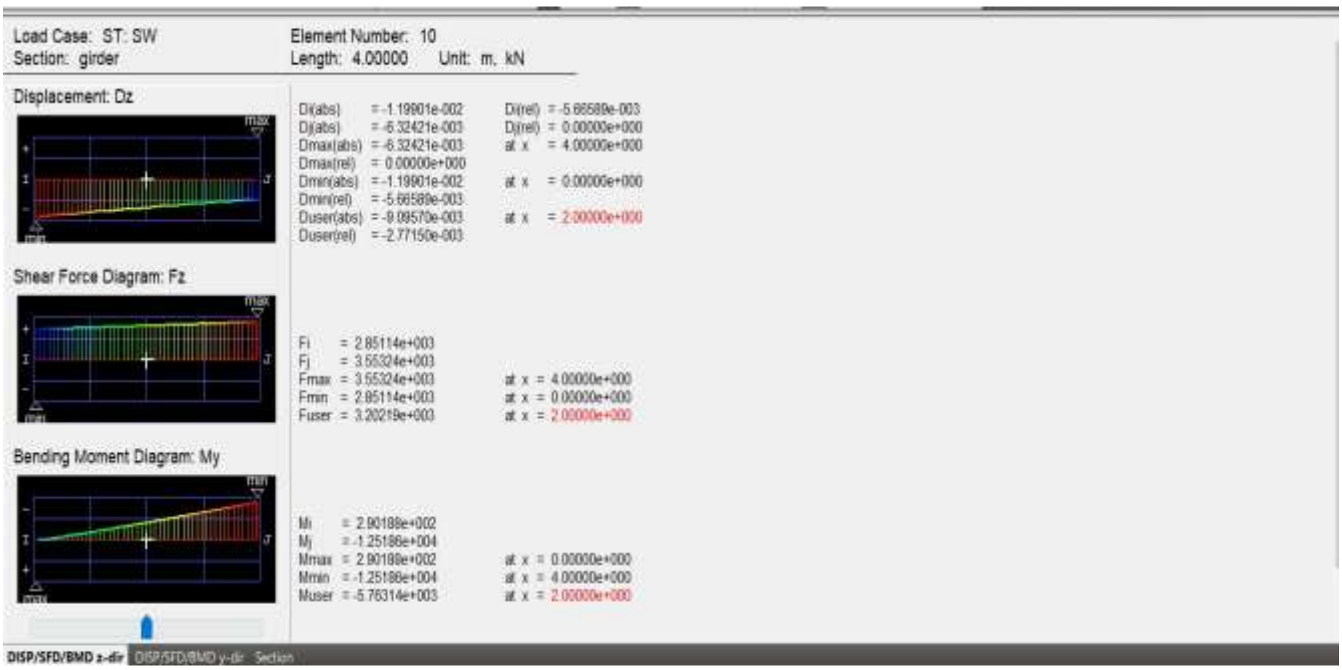
M_{ult}= 0.9 d_b A_s f_p

A_s = the area of high tensile steel

f_p = the ultimate tensile strength for steel without definite yield point or yield stress or stress at 4 per cent elongation whichever is higher for steel with a definite yield point.

d_b = the depth of the beam from the maximum compression edge to the centre of gravity of the steel tendons.

M_{ult} = 0.9×350×1340×862= 25654 kNm > 22195 kNm (moment obtained manually) Hence safe.



Failure by crushing of concrete,

M_{ult} = 0.176 bd_b2 f_{ck} (for rectangular section)

M_{ult} = $(0.176b_wd^2f_{ck}$ + 0.67□.8(b -b_w)(d-0.5D_f) f_{ck}) (for Tee sections).

B = the width of rectangular section or web of a Tee 0.8beam.

B_f = the width of flange of Tee beam. t =thickness of flange of Tee beam.

M_{ult} = (0.176□00□3502) + [(0.67□) (200 -300) (1350-0.5□00) (300□0)]

= 25454 kNm > 22195 kNm (moment obtained manually). Hence safe.

Mid-support section Failure by yield of steel,

M_{ult}= 0.9 d_b A_s f_p

M_{ult} = 0.9□700□1340□862

= 32306 kNm > 30110 kNm (moment obtained manually) Hence safe.

M_{ult} = (0.176b_w d^2 f_{ck} + 0.67□.8 (b -b_w) (d-0.5D_f) D_f f_{ck})

=[(0.176□00□7002□0]+[(0.67□)(2000 - 300)(1700-0.5□00)(300□0)]

= 34577 kNm > 30110 kNm (moment obtained manually) Hence safe.

The ultimate flexural strength of center of span and mid support section are greater than the required design ultimate moments. Hence, the design satisfies the limit state of collapse.

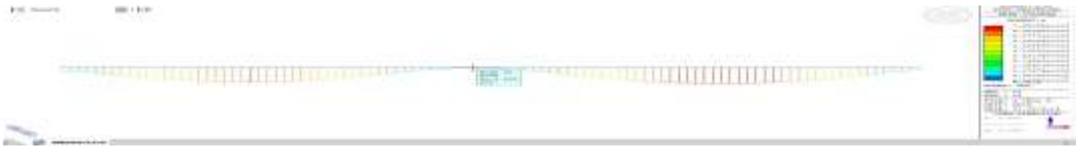


Figure 3.9 Bending moment of continuous beam

Figure 3.10 Bending moment of cable

3.11 Reinforcements

Longitudinal reinforcement of not less than 0.18% of gross cross-sectional area are to be provided according to the specification of IRC 18-2000 to safeguard against shrinkage cracking in webs.

A_{st} = 0.0018□000□00 = 540mm ^{2}

Provide 12mm diameter bars at 160mm centers

4. RESULTS AND DISCUSSIONS

The four cell prestressed girder is analyzed by MIDAS CIVIL software and the loading standards are as per IRC: 6-2014.The result is analyzed for straight and parabolic cable profile for segments 5 to 7.

Figure 4.1 Displacement, shear force and bending moment for element 10

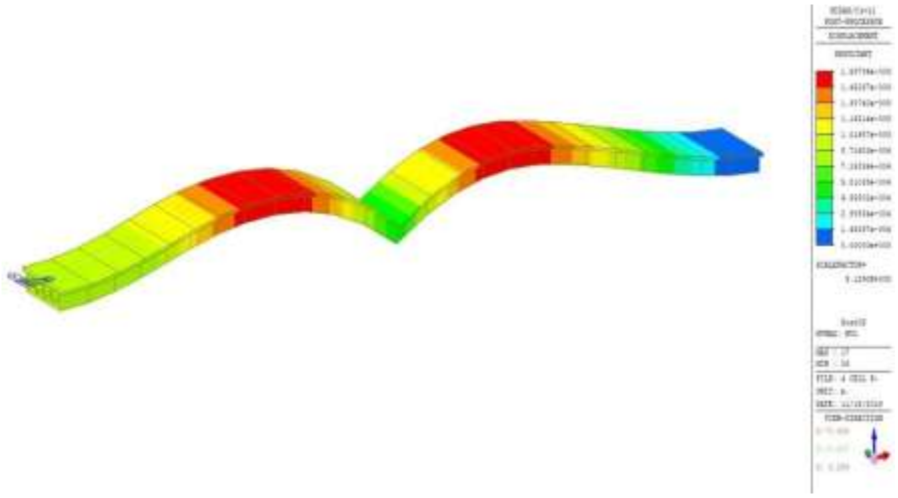


Figure 4.2 Displacement after applying load

Parabolic tendon profile		Straight tendon profile	
FT (N/mm²)	FB (N/mm²)	FT (N/mm²)	FB (N/mm²)
1.7425	-8.3043	9.2712	-10.086
1.1087	-7.6331	7.4116	-8.3395
1.1087	-7.6331	7.4116	-8.3395
0.3136	-6.737	5.3576	-6.3366
0.3136	-6.737	5.3576	-6.3366
-0.6127	-5.6979	3.1737	-4.1958

Table 4.1 Stress at top and bottom for parabolic tendon profile and straight tendon profile

Element	Max/min Shear	Shear force (VEd) (kN)	Design shear force (VRd) (kN)
5(I)	Max	2452.0975	3884.436
5(J)	Min	1139.3902	4511.624
5(I)	Max	2746.2034	3938.62
5(J)	Min	1374.6152	4318.866
6(I)	Max	2746.2034	3938.62
6(J)	Min	1374.6152	4318.866
6(I)	Max	2864.0792	3767.733
6(J)	Min	1623.2155	3997.467
7(I)	Max	2864.0792	3767.733
7(J)	Min	1623.2155	3997.467
7(I)	Max	3122.4528	3682.507
7(J)	Min	1753.5032	3792.336

Table 4.3 Maximum and minimum shear force (straight tendon profile)

Element	Max/min Shear	Shear force (VEd) (kN)	Design shear force(VRd) (kN)
5(I)	Max	1244.5122	1568.23
5(J)	Min	67.9994	203.56
5(I)	Max	1538.8881	1789.157

5(J)	Min	166.9416	349.6464
6(I)	Max	1538.8881	1948.865
6(J)	Min	166.9416	484.8491
6(I)	Max	1657.0541	2519.949
6(J)	Min	416.0114	984.849
7(I)	Max	1657.0541	2546.166
7(J)	Min	416.0114	792.166
7(I)	Max	1915.1466	2648.45
7(J)	Min	545.3072	947.5456

Table 5.4 Maximum and minimum shear force (parabolic tendon profile)

4.1 Discussions

1. From results the straight tendon profile produces more stress at top and the shear force is also greater than parabolic tendon profile.

2. Based on load balancing concept for uniformly distributed loads the parabolic tendon profile reduces the stresses than straight tendon profile.

5. CONCLUSION

- The straight and parabolic tendon profile was created for the four cell prestressed girder and study on the effect of eccentricity, Prestressing force and Cable profile.

- The structural static properties such as deflections and stress distributions was studied for the above girder.

- The deflection due to the application of live load at critical section is 7.5 mm for straight tendon profile and 7.06mm for parabolic tendon profile.

- Stress due to loads at critical section for parabolic profile is 1.745 N/mm2 and for straight cable profile 9.217 N/mm2.

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