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Parametric study on analysis and design of precast segmental box girder type superstructure of bridge

Shivani Ranje[1], B.J. Shah[2], P.H, Andharia[3]

Student, Structural Engineering, L.D. College of Engineering, Ahmedabad, India[1]

Principal, GEC Modasa, Modasa, India[2]

Assistant Professor, Applied Mechanics, L.D. College of Engineering, Ahmedabad, India[3]

Abstract: Precast segmental box girder type superstructure bridges are extensively constructed in urban areas. In this project Balanced cantilever method is used for model generation of precast segmental box girder bridge using MIDAS CIVIL 2019.Parametric study is carried out considering different span to depth ratio (at support and at mid-section) and different span length. construction stage analysis has also been carried out. Span to depth ratios for support section are taken as 16,15,14and that for mid-section are 50,40,30 is considered. different span length has been considered as 60,70,80 different grade of concrete M50, M55, M60 considered. Different type of tendon bonded and unbonded also considered. Analysis result show that shear force and bending moment increases with increase in length of the span of bridge. S.F. and B.M. increases on support segment with increase in depth at support section while depth at mid-segment keeping constant, while the same decrease at mid-segment. Bonded tendon gives less bending moment, shear force and deflection as compare to bonded tendon, so bonded tendon is more suitable than unbonded tendon. M50 grade of concrete not satisfy combine shear and torsion criteria which satisfied by M55 and M60 grade of concrete, so grade of concrete above M50 is require. Span to depth ration at support and mid segment 16,15,14 and 50,40,30 respectively satisfy all ultimate limit state and serviceability criteria and therefore this ranges of span to depth ratio suitable for safe design.

Keywords: Precast segmental bridge, balanced cantilever method, parametric study, post tensioning

I. INTRODUCTION

Segmental concrete bridges are bridges which involves assemblage of smaller pieces of concrete members called segments using post tensioning tendons to form a bridge structural system, either superstructure or substructure. the posttensioning system can be bonded, unbonded tendons, or a combination of both.it can be external or internal. Segments can be produced by cast-in-place or precast/prefabricated methods. There are mainly three construction method for the precast segmental bridge which are balanced cantilever construction method, span by span construction method and incremental launching method. From above three I have selected balanced cantilever construction method. Economical span length range of precast segmental box girder balanced cantilever bridge ranging from 40 to 110 m. it also gives aesthetic looks and it is a cost-effective method. Cast-in-place balanced cantilever bridges are especially suitable for construction of long spans over deep valleys and rivers where placing temporary supports is not possible or cost prohibitive. Some advantages of precast segmental bridge over cast-in-place construction are the speed of superstructure erection, less creep and shrinkage effect, and better-quality control when casting segment in the casting yard. Precast segment element cast by long line and short line casting method. Typical segment length ranging from (3 to 4.9 m). It is important to limit the segment weight to about 60 t (534 KN) to 80 t (712 KN), since it impacts the erection equipment capacity to lift and place the segment in place. Segment erected over pier is called pier table which is generally consist three segments. As moving outward from pier table on both opposite side segment length increases and depth decreases to maintain weight of each segment. For prestressed concrete bridge grade of concrete above M35 in moderate condition and above M40 in severe condition required as per IRC 21:2000 codal provision. Two cantilevering tips join by cast in situ stich called key segment. The deck of bridge self-supporting during construction and it also support erection equipment. negative moment governs balanced cantilever construction, and this often requires box section with a thick bottom slab at the root of cantilever and many longitudinal tendons at the top slab. Balanced cantilever bridges typically have box section. The bottom slab of a box girder lowers the cross-sectional center of gravity, which increases the flexural capacity in negative bending moment regions. Single cell box girders may reach 18 to 20 m of width, further widening can also possible by providing transverse ribs in the top slab and diagonal struts propping the edges of the side wings from the bottom slab-web of the

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cross section. Different parametric variation gives different effect on design and analysis of bridge. Bridge "aesthetics" with "economy" is a challenging task for engineers. Superstructure plays a leading role in bridge aesthetics and economy. Many times, it is the only option left for "Construction of Bridge in Difficult Climate Region" and "Construction of flyover without disturbing traffic".

A. Sectional properties

- Grade of concrete
  (from IRC: 21 :2000, Table – 5)

Condition of exposure	
Moderate	severe
M35 at 28 days	M40 at 28 days

Table 1 concrete grade

- Minimum thickness of web (IRC: 18:2000, cl. 9.3.2.2)
  - (d/36) + 2(clear cover to reinforcement) + diameter of duct holes
  - 200 mm + diameter of duct holes
  - Where, d = overall depth of box girder from top of slab to Bottom of soffit.
  - Whichever is greater is taken as minimum thickness of web.
- Minimum thickness of bottom flange of box girder (IRC: 18:2000, 9.3.2.3)
  - 1/20 (clear web spacing at junction with bottom flange)
  - 200 mm
  - Whichever is more is taken.
- Minimum thickness of top flange and deck slab (IRC: 18:2000, 9.3.1.3)
  - 200mm
- Minimum Thickness of top and bottom flanges having prestressing cables
  - 150 + diameter of duct holes
- Haunches of minimum size 300 mm horizontal and 150 mm vertical
- The minimum clear height of inside the box girder shall be 1.5 m to facilitate inspection.
- Moving load definition and load combination are from IRC:6-2017
- Coefficient of thermal expansion of steel = $7.2 * 10^{-6}$ 1/F
- Modulus of elasticity = $2 * 10^{8}$ KN/m^{2}

II. PARAMETRIC VARIATION

A. Parameters

- Span length variation L = 60,70,80 m taken
- Support section depth variation L/D1 = 16,15,14
- Mid section depth variation L/D2 = 50,40,30
- Tendon type = internal bonded and unbonded
- Grade of concrete = M50,M55,M60

B. Modelling

Modelling and analysis of 3 span continuous precast segmental balanced bridge is done using MIDAS civil 2019 software. Taking mid span length 60 m, span to depth ratio at mid and support section,grade of concrete, tendon type total 11 model created and analysed. And for span variation other 3 model taking span length 60m,70m,80m created and analysed. Each model satisfy ultimate limit state and serviceability limit state criteria. L is the span length, D1 is the depth at support section and D2 is depth at mid section. Pier table consist 3 segment.

Support section depth variation					Mid-section depth variation				
SPAN	L/D1	L/D2	D1	D2	SPAN	L/D1	L/D2	D1	D2
60	16	40	3.75	1.5	60	16	40	3.75	1.5
60	15	40	4	1.5	60	15	40	4	1.5
60	14	40	4.30	1.5	60	14	40	4.30	1.5

Table 2 Depth variation

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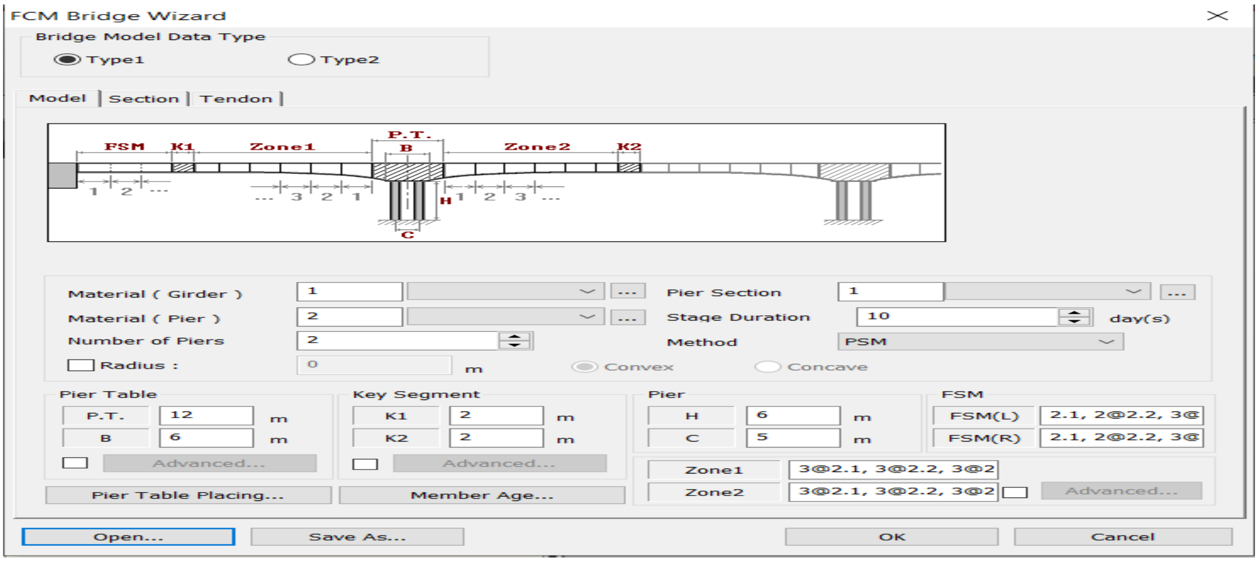

Figure 1 dimensioning

For 60 m span

- Width of road = At top 12m and bottom flange 6.6m
- End span = (0.7 to 0.85) L = 42 TO 51 Taken = 45 m
- Zone – 1 = zone - 2 = 23 = 3@2.1,3@2.2,3@2.5,1@2.6
- Length of pier table = 12 m
- Pier dimension = 8.5 * 3.5 m at c/c 5m
- Tendon = 7 ply 15.2 mm 19 no. = area = 0.0026353 m2
- Concrete grade = M60
- Weight density of tendon = 76.98 KN/m^3
- Ultimate strength of tendon = 1.862*10^6 KN/m^2
- Mid span = L = 60m
- Total length of bridge = 45+60+45 = 150 m
- FSM zone = 14 m = 1@2.1,2@2.2,3@2.5
- Length of key segment = 2 m
- Height of pier = 6m
- Steel = Fe 500
- Poissons ratio = 0.3
- Duct diameter = 0.103
- yield strength of tendon = 1.650 * 10^6 KN/m^2
- Gantry load = 500 KN with eccentricity 1.5 m excluding self weight of wet concrete
- Two types of vehicle load combination ,2 lane of IRC Class A & 1 lane of 70 R
- Stage duration = 10 days, for creep and shrinkage stage duration for full staging taken as 10000 days
- For CLASS 70 R loading, eccentricity = e = 3.75-1.2-1.45 = 1.1 m, Wheel spacing = 2.9-0.84 = 2.06
- For 2 lane of CLASS A loading, Lane left , eccentricity= 3.75-0.150-1.15 = 2.45 m, Lane right, eccentricity = 0.150+2.3+1.2+1.15-3.75 = 1.05

For 70 m span

- D1 = L/16 = 70/16 = 4.375 TAKEN 4.375
- D2 = L/50 TO L/30 = 70/50 TO 70/30 = Taken 1.75
- End span = (0.7 to 0.85) L = 49 TO 59.5 = Taken 50 m
- Zone -1 = zone – 2 = 28 = 3@2.5,3@2.7,3@3,1@3.4
- Mid span = 70
- Total length of bridge = 70+50+50 = 170 m
- Fsm zone = 14 = 2@2.5,3@3
- all other dimensions are same as above

For 80m span

- D1 = L/16 = 80/16 = 5 m
- End span = (0.7 to 0.85) L = 56 to 68 = taken 60 m
- Total length of bridge = 60+80+60 = 200 m
- Zone – 1 = zone – 2 = 33 = 3@2.5,3@3,3@3.2,2@3.45
- D2 = 80/40 = 2 m taken
- Mid span = 80
- Fsm = 19 = 4@2.5,3@3
- All othet dimension are same as above

Superimposed dead load calculation

- Density of wearing coat material = 2.20 t/m3 . = 22 kn /m3
- Density of material for crash barrier = 2.50 t/m3 = 25 Kn/m3
- Density of Footpath material = 2.30 t/m3 = 23 kn/m3
- Thickness of wearing coat = 80 mm (assumed)
- Height of crash barrier = 1 m
- Dimension of footpath = 1.50*0.30 m
- Cross section area of crash barrier = 0.50*1 = 0.50 m ^{2}
- UDL longitudinal direction due to wt. of wearing coat = 0.080*7.5*22 = 13.2 kn/m
- Udl longitudinal direction due to wt, of crash barrier = 0.50*25 = 12.5 kn/m
- Udl longitudinal direction due to wt. of footpath = 1.50*0.30*23 = 10.35 kn/m
- Total SIDL = 13.2+12.5+10.35 = 36.05 KN/m

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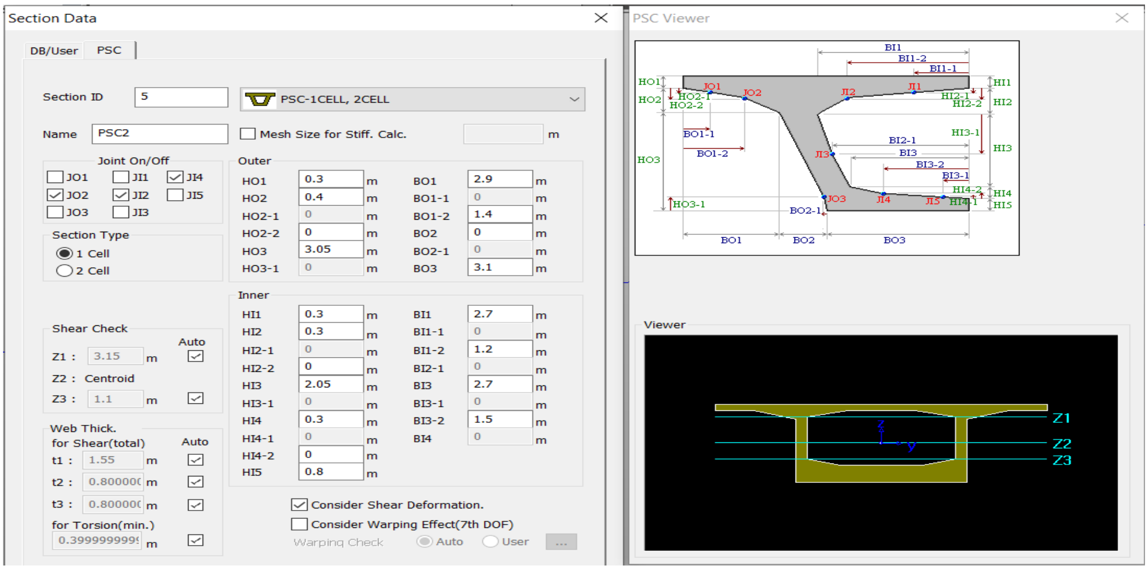

Figure 2 Box cross section dimention at support section

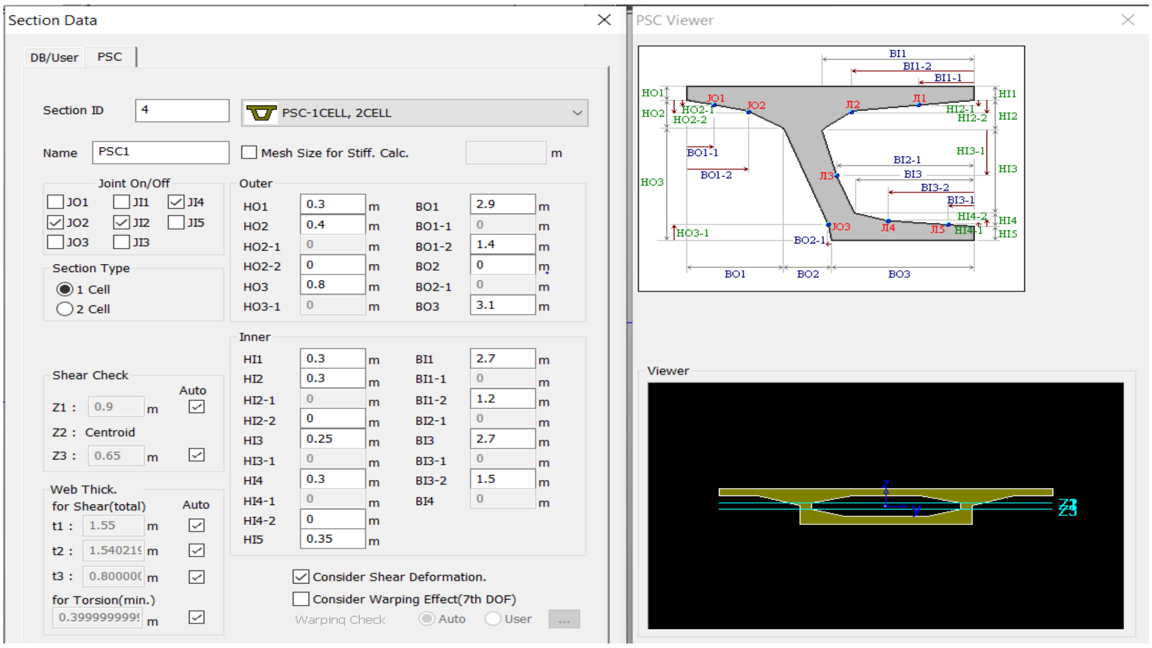

Figure 3 Box cross section dimension at mid section

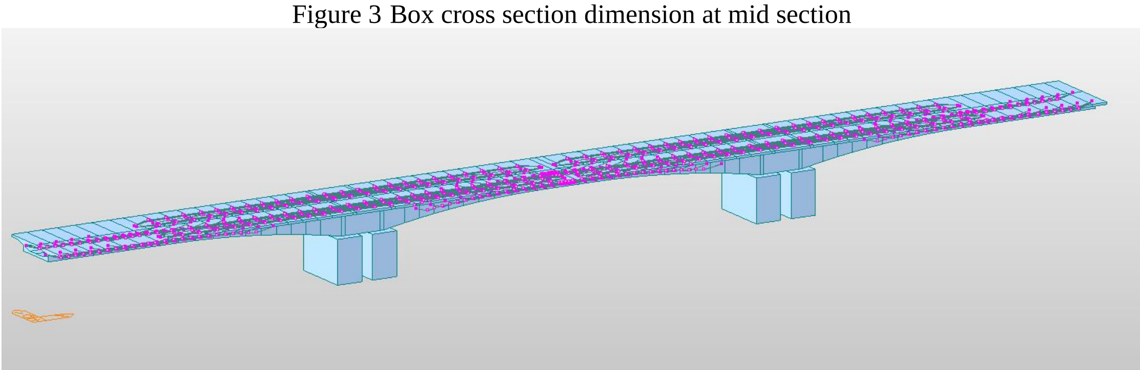

Figure 4 Tendon layout

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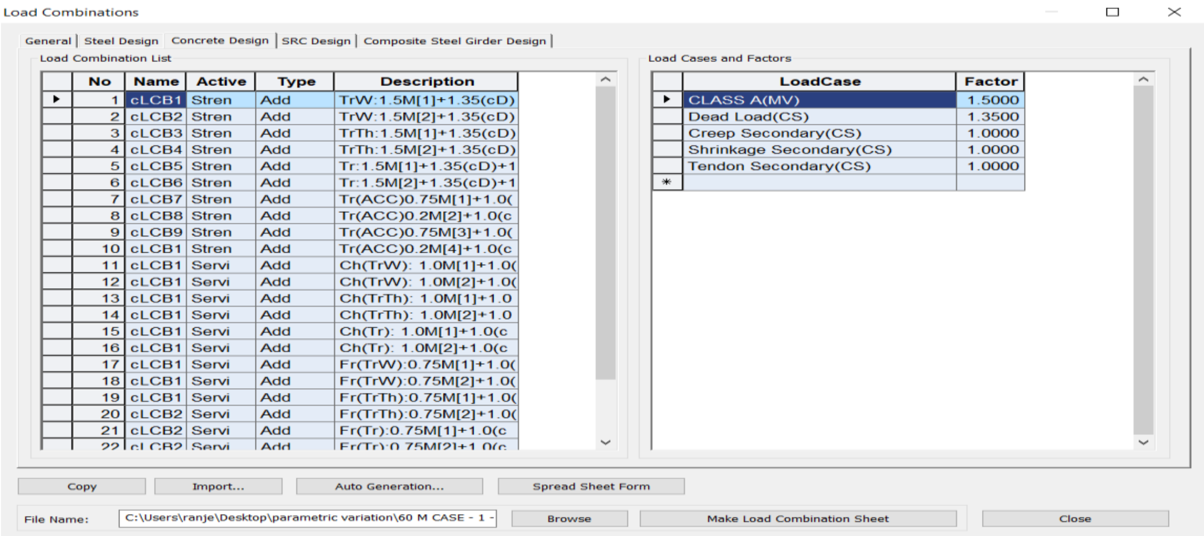

Figure 5 load combination

There are total 24 load combination and each model analysed for each load case and maximum bending moment, shear force, axial force, deflection find out and compared for each model.

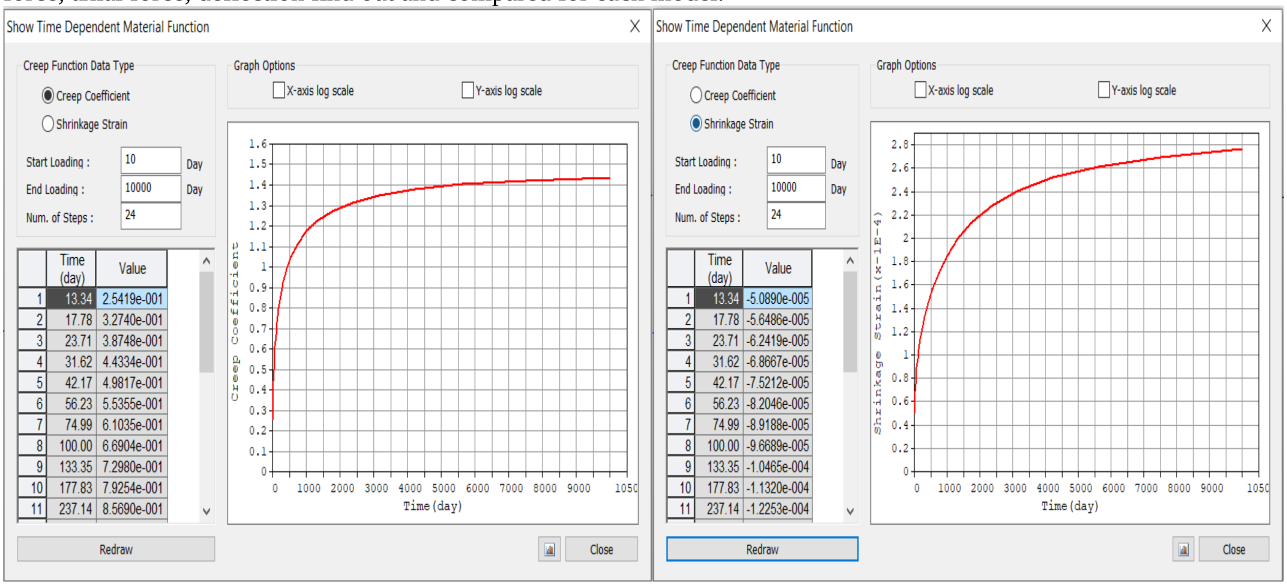

Figure 6 creep and shrinkage definition

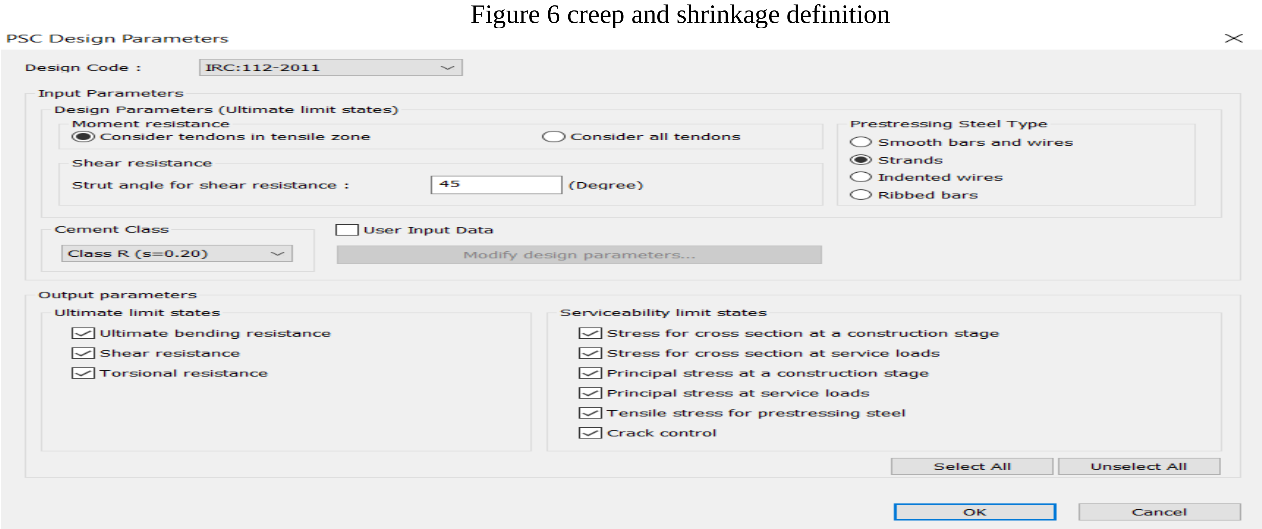

Figure 7 PSC design parameters

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III. RESULTS

A. CONCRETE GRADE VARIATION

- COMBINE SHEAR AND TORSION CRITERIA

$T_{Ed} / T_{Rd,max} + V_{Ed} / V_{Rd,max} \leq 1.0$ (IRC:112 : 2011)
T_{Ed} = Applied torsional moment $T_{Rd,max}$ = Maximum resisting torsional moment by section
V_{Ed} = Applied shear force $V_{Rd,max}$ = Resisting shear force by section

Grade of concrete	Location	Vrd (max) (KN)	Ved (KN)	Trd (max) (KN.m)	Ted (KN.m)
M 50	20 (i)	17762.951	20794.018	143799.290	79.712
M 55	20 (i)	19163.492	3796.225	155137.311	1674.334
M 60	20 (i)	20495.713	3798.574	165922.258	75.412

Table 3 interpretation of grade variation results

Grade of concrete	Value of criteria	Condition
M 50	1.171	Not satisfied
M 55	0.208	satisfied
M 60	0.1857	satisfied

Table 4 Results of concrete grade variation

- For M50 grade of concrete combined shear and torsion criteria not satisfied for support segment. Therefore grade of concrete above M50 suitable.

B. Results of support section span to depth variation

SPAN	CASE	L/D1	L/D2	D1	D2	B.M.(KN.m) (hogging)	S.F. (KN)
60	1	16	40	3.75	1.5	$1.5856*10^6$	$1.3754*10^4$
60	2	15	40	4	1.5	$1.5885*10^6$	$1.3818*10^4$
60	3	14	40	4.30	1.5	$3.1093*10^6$	$4.1266*10^4$

Table 5 variation in bending moment and Shear force

SPAN	CASE	L/D1	L/D2	D1	D2	B.M. (KN.m) On support segment	B.M. on mid segment (KN.m)
60	1	16	40	3.75	1.5	$-1.4515*10^5$	$3.7933*10^4$
60	2	15	40	4	1.5	$-1.5885*10^5$	$3.7281*10^4$
60	3	14	40	4.30	1.5	$-2.0009*10^5$	$3.2238*10^4$

Table 6 effect of support depth variation on mid and support section bending moment

SPAN	CASE	L/D1	L/D2	D1	D2	S.F. on support segment (KN)	S.F. on mid segment (KN)
60	1	16	40	3.75	1.5	$-7.839*10^3$	$5.790*10^3$
60	2	15	40	4	1.5	$-8.294*10^3$	$5.478*10^3$
60	3	14	40	4.30	1.5	$-28.489*10^3$	$5.229*10^3$

Table 7 Effect of support depth variation on mid and support section shear force

- S.F. and B.M. increases on support segment with increase in depth at support segment while depth at mid segment keeping constant, while the same decrease at mid segment.

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C. Span variation

Span (m)	MAX BM (KN.m)	MAX SF (KN)	Axial force (KN)	Deflection(mm)
60	-158564.8	13754.8	-117136	59.505
70	-337146.9	49120.8	-109159	63.524
80	-695110	85853.9	-108891	75.112

Table 8 Results of span variation

- As span increases bending moment, shear force and deflection increases while axial force decreases.

D. Variation in type of tendon

TENDON TYPE	MAX BM (KN.m)	MAX SF (KN)	Axial force (KN)	Deflection(mm)
bonded	-158564.8	13754.8	-117136	59.505
unbonded	-331554.2	46170.2	-107247	63.754

Table 9 results of tendon type variation

IV. CONCLUSION

- Grade of concrete above M 50 required
- span to depth ratio at support section 16 to 14 and that for mid-section 50 to 30 satisfy ultimate limit state and serviceability limit state criteria, so this range of ratios suitable for safe design.
- As depth at support section increases from 3.75 to 4 m and 4 to 4.30 m absolute maximum bending moment increase by 0.18% and 48% and shear force coming on bridge increases by 0.46% and 66% respectively.
- S.F. and B.M. increases on support segment with increase in depth at support segment while depth at mid segment keeping constant, while the same decrease at mid segment.
- As span increases from 60 to 70m and 70 to 80 m bending moment increase by 52.96% and 51.49%, shear force increase by 72% and 42.78% and deflection increases by 6.32% and 11.59% while axial force decreases by 6.81% and 0.23% respectively.
- Bending moment increase by 52%, shear force increases by 70.21%, deflection increase by 6.66% and axial force decrease by 8.44% in case of unbonded tendon as compared to bonded tendon.so bonded tendons are more suitable.
- As depth at mid-section increases from 1.2 to 1.5 m and 1.5 to 2 m absolute maximum bending moment increase by 16.28% and 50.56% and shear force increase by 11.63% and 69.38% respectively.
- As depth at mid segment increases from 1.2 to 1.5 m and 1.5 to 2 m deflection decreases by 12.12% and 11.32%.

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