

BUCKLING ANALYSIS AND REINFORCEMENT DETAILING OF SLOTTED BRIDGE PIER

Krunalsinh Virpura¹, Snehansu Nath²

¹Dept. of Civil Engineering, Parul University, Vadodara, Gujarat.

²Associat Professor, Dept. of Civil Engineering, Parul University, Vadodara, Gujarat.

Abstract - Slotted bridge pier can eliminate scouring amount at a great extent. The Bridge pier is axially loaded member so, it is necessary to do buckling analysis for checking its vertical stability and displacement under maximum applied load. Slotted Bridge Pier can take load just similar of solid circular bridge pier but need to provide suitable pattern of reinforcement. By taking same percentage of reinforcement used in normal circular bridge pier, reinforcement pattern of Slotted Bridge Pier can be design. In reinforcement detailing of SBP, must need to design slab over slot to take excessive weight of concrete over slot. When SBP is under loading condition maximum stress develop at middle of bridge pier i.e. just at top of slot. To encounter this riddle, provided suitable reinforcement pattern.

Key Words: Buckling analysis, Reinforcement detailing, Displacement, slab reinforcement, stability Of SBP, Reinforcing as a column.

1. INTRODUCTION

When discussing about the infrastructure in India, and more specifically, the problem facing India's infrastructure, Bridges failure have been one of the leading problem facing India's infrastructure. Bridge failures are costly in the construction, lives lost, and replacement funds required rebuilding failed bridges.. Till now many of bridges get collapse/failed over water bodies. The flow of water in a river and streams excavates and moves materials from bed and banks of streams and from around the bridge pier and abutments. Correspondingly, foundation of the structures are undermined by this erosive action of the flowing water which is named as Scour (see fig. 1) [1]

Scouring may severely damage the pier of bridge or sometimes it'll collapse the bridge too. CHADOORA Bridge located at Teshil Chadoora in Kashmir (J&K), LANGI DURG Road Bridge in Balaghat district (Madhya Pradesh), JAHU Bridge (Himachal Pradesh), Bridge on Savitri River (Maharashtra) Collapsed in 2016, 30 major as well as minor bridges (Kashmir) collapsed in 2014 and many more. These are the few examples of failed/collapse bridges due to scouring action around bridge pier as well as in its foundation.

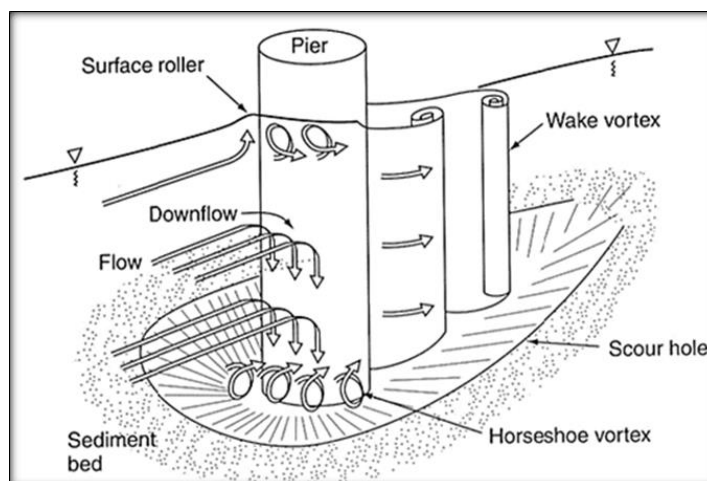


Figure 1 Mechanism of Scouring Around Circular Bridge Pier

Yee-Meng Chiew Suggested one of the best countermeasure to reduce the scoring 1992. He had suggested unique type of bridge pier named Slotted Bridge Pier in his Research work on SCOUR PROTECTION AT BRIDGE PIERS. As per his Research work

he had constructed slot through a bridge pier, either near the bed or near the water surface [see Figs. 1(a) and (b)]. A slot near the bed [Fig. 1(a)] diverts the down-flow through the slot opening, thus reducing its erosion potential. A slot near the water surface [see Fig. 1(b)] allows near-surface water to pass through the slot opening, thereby creating a similar effect as a lower flow depth. The lower effective flow depth has an important influence on the depth of scour. Experiments showed that it is very effective in reducing scour depth. By placing a one-fourth diameter wide slot near the water surface or the bed level, it is possible to reduce the clear-water scour by as much as 20%. A one-half-diameter-wide slot placed near the water surface can reduce the clear-water scour depth by as much as 30%. [2]

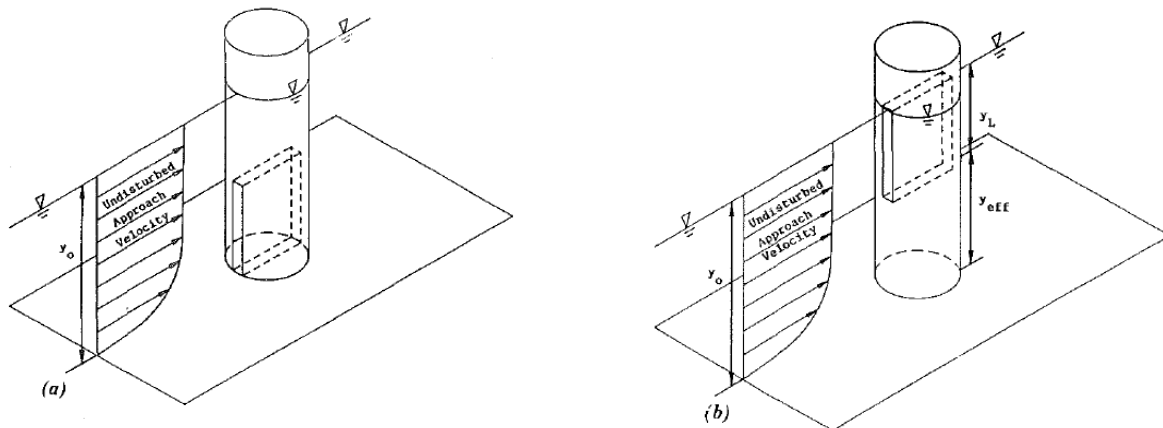


Figure 2(a) Bridge Pier with Slot near sediment bed (b) Bridge Pier near Water surface

1.1 Literature Review

Ali khudabakshi et al Studied in their experiment, when height of slot is below the stream bed it proves more effective on reducing scouring amount. As a result scouring depth will be reduced up to 20.34% to 39.73% and scour volume approximately 46.89% to 75.74% when slot is provided at the bed of stream [3].

M. Osroush et al examines that when slot in abutment placed closer to the bed, it would be more effective in reduction of Scouring. Also experimented that if the height of slot is higher than the depth of were showed a batter performance [4].

Kumar et al investigated the reduction of local scouring around Bridge pier in a direct stream with the use of a slot and collar. Their results shows that the slot was effective in reducing scoring but slotted pier would not be effective if flow approaching the pier shows great deviation [5].

A.T. Moncada-M et al had found that when the collar was placed at the bed level, the minimum scoured depth reached, also investigated the scour depth is inversely proportional to the diameter of the collar. In future result they added that if slot is placed near to the bed level, it found most effective in reducing scouring depth, in future comments they said that if slot length increases the scouring depth decreases. When applying the collar and slot combination scouring depth almost entirely eliminated [6].

M. Heydarnejad et al investigated effect of slot on scouring around pier in different position of 180-degree bends and as a conclusion found that reduction in scour depth is 24% [7].

Hooman Hajikandi et al performed various experiment on Y-slot and T-slot bridge pier in comparison with simple straight bridge pier. [8]

Heydarpour et al The findings revealed that the group of bridge piers has a great impact on the depth of scouring on the rear part of the pier compared with an individual pier. They also concluded that the effect of the slot on reducing scouring depth increases in parallel with the increase in the pier area, also added that if spacing between the piers increases, unprotected area between piers is washed away resulting deeper scour holes at the rear piers. [9].

Carmelo Grimaldi et al experimented that slot may reduce local scour depth at bridge pier about 30% (about 70% for both scour area and volume). In addition also experimented that combination of slot and bed sill at downstream of the river can reduced scour depth approximately 45% (about 80% and 90% for scour area and volume, respectively) [10].

2. METHODOLOGY

In the first phase, we've consider control model of bridge pier i.e. the bridge pier with no slot condition. We've to do the comparison of buckling factor as well as lateral displacement between slotted bridge pier and control model at the end of the work to get the appropriate result about the vertical stability of slotted bridge pier.

After deciding the parameters i.e. size of control model (bridge pier with no slot condition), we've calculate intensity of loads that are going to be applied on control model. So, we took dead load, live load in the account and applied vertically on control model. In Post-processing mode we got the percentage of longitudinal reinforcement for control model.

Now, in the next phase we need to calculate same percentage of longitudinal reinforcement that we got from control model, that same percentage of steel we had rearrange in slotted bridge pier with different pattern. Later-on control model with reinforcement is analyzed in ABAQUS software by FEM, and in the result we got lateral displacement as well as buckling factor.

In further steps, slotted bridge pier with different pattern of rebar is analyzed in ABAQUS software and as an output we aim to get result just similar to the control model. I.e. lateral displacement and buckling factor of slotted bridge pier. So that we could comment on its vertical stability.

Now, in subsequent phase we've compare results of both slotted bridge pier and control model aim to get vertical stability of slotted bridge pier over control model under same amount of load, and if we can't get such result, so that we need to change pattern of reinforcement for slotted bridge pier and again analyzed it in ABAQUS.

Repeated the above step till the appropriate result comes.

3. STRUCTURE CONFIGURATION

3.1 Parameters:

Characteristics of concrete:

- Grade of concrete (f_{ck}) = M25
- Elasticity of concrete (E) = $500 (f_{ck})^{1/2}$ N/mm²
- Poisson's ratio of concrete (μ) = 0.1 to 0.2
- Density of concrete (ρ) = 2400 Kg / m³

Characteristics of steel:

- Grade of steel (f_{st}) = fe415
- Elasticity of steel (E_s) = $2 * 10^5$ N/mm²
- Poisson's ratio of steel (μ_s) = 0.3
- Density of steel (ρ_s) = 7850 Kg / m³

1) **Span of Bridge** = 40 m

2) **Size of Control Model:**

Diameter (D) = 5 m

Height (H) = 10 m

3) **Parameters of Slotted Bridge Pier:**

Diameter of SBP (D0) = 5 m

Height of SBP (H0) = 10 m

4) Size & position of Slot in SBP:

Yee-meng-chiew (1996) concluded that the width of the slot in pier is equal to the one-fourth of the diameter of the bridge pier and height of slot is equal to the one-half diameter of pier can be more effective in reducing the scouring amount. Also shows that if slot is placed near to the bed level it can be eliminate scouring in more amount.

So,

- ❖ Width of Slot = $\frac{1}{4}$ diameter of SBP
 $= \frac{1}{4} * 5$
 $= 1.25 \text{ m}$
- ❖ Height of slot = $\frac{1}{2}$ of Height of SBP
 $= \frac{1}{2} * 10$
 $= 5 \text{ m}$
- ❖ Slot is placed at a bed level in SBP.

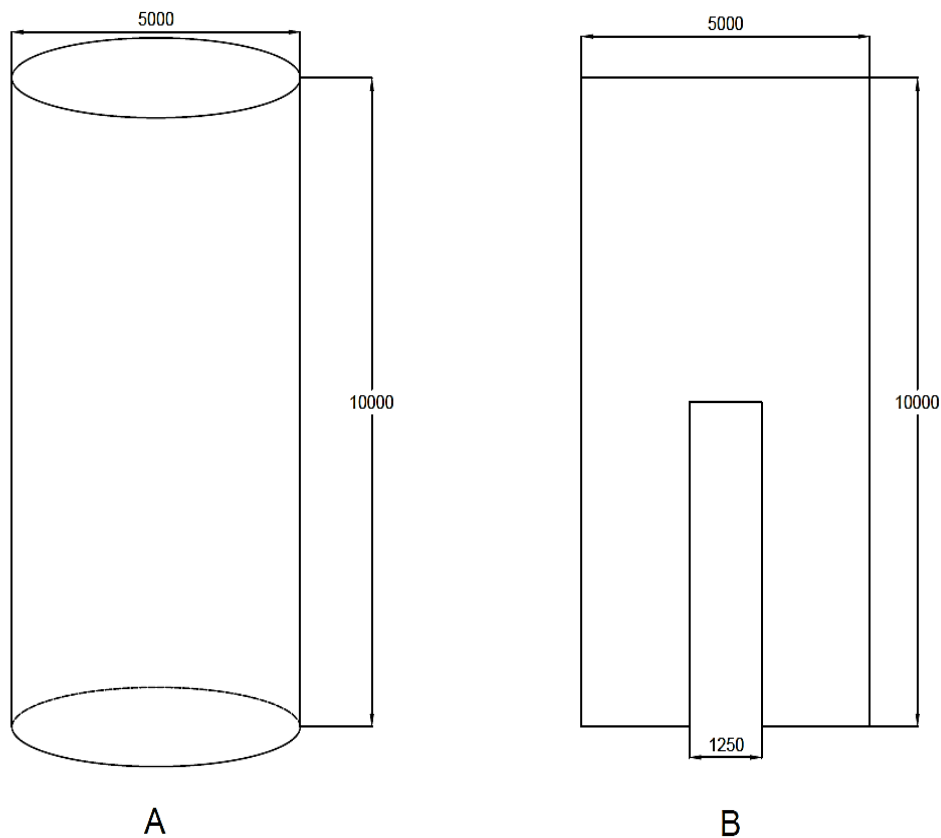


Figure 3 Cross section of (A) Control Model & (B) Slotted Bridge Pier

3.2 Load calculation:

1) Dead Load:

In calculation of dead load (DL) which is acting on control model as well as SBP, It comes from the self-weight of its super structure.

Box Girder consider as a super structure and the cross section of Box Girder is given in figure below.

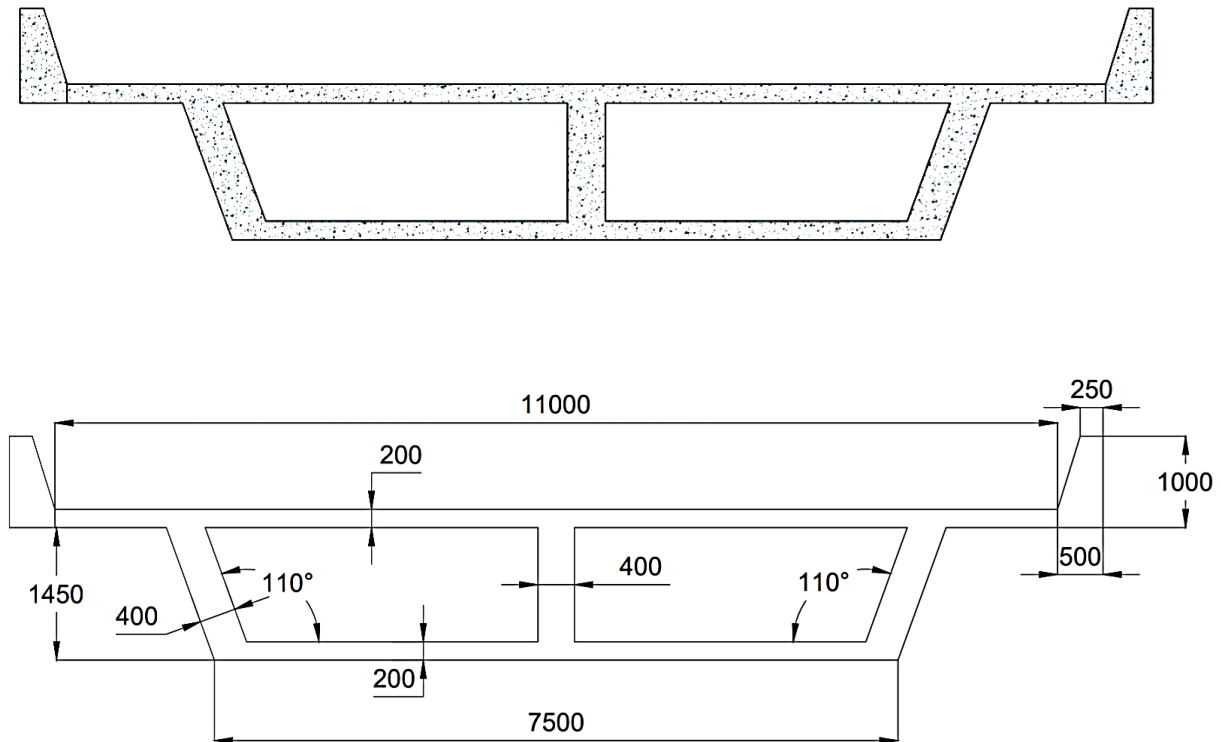


Figure 4 Cross section of Box Girder

- ❖ Cross sectional area of Box Girder = 6.08 m²
- ❖ Span of box girder = 40 m
- ❖ Density of RCC = 25 KN/m³

So,

- ❖ Self-weight of Box Girder = 6.08 * 25
= 152 KN/m

- ❖ Dead load acting on pier due to Box Girder = 152 * 4
DEAD LOAD = 6000 KN

2) Live Load:

As per IRC: 6 - 2014, [11]

In Annex A, Class AA tracked and wheeled vehicles load is given, which is given in below figure.

Maximum load for the tracked vehicles shall be 35 tones for a single axle or 70 tones for a bridge of two axles spaced not more than 1.2m centers.

So, Maximum Live Load going to be applied that taken as 70 tones
= 700 KN

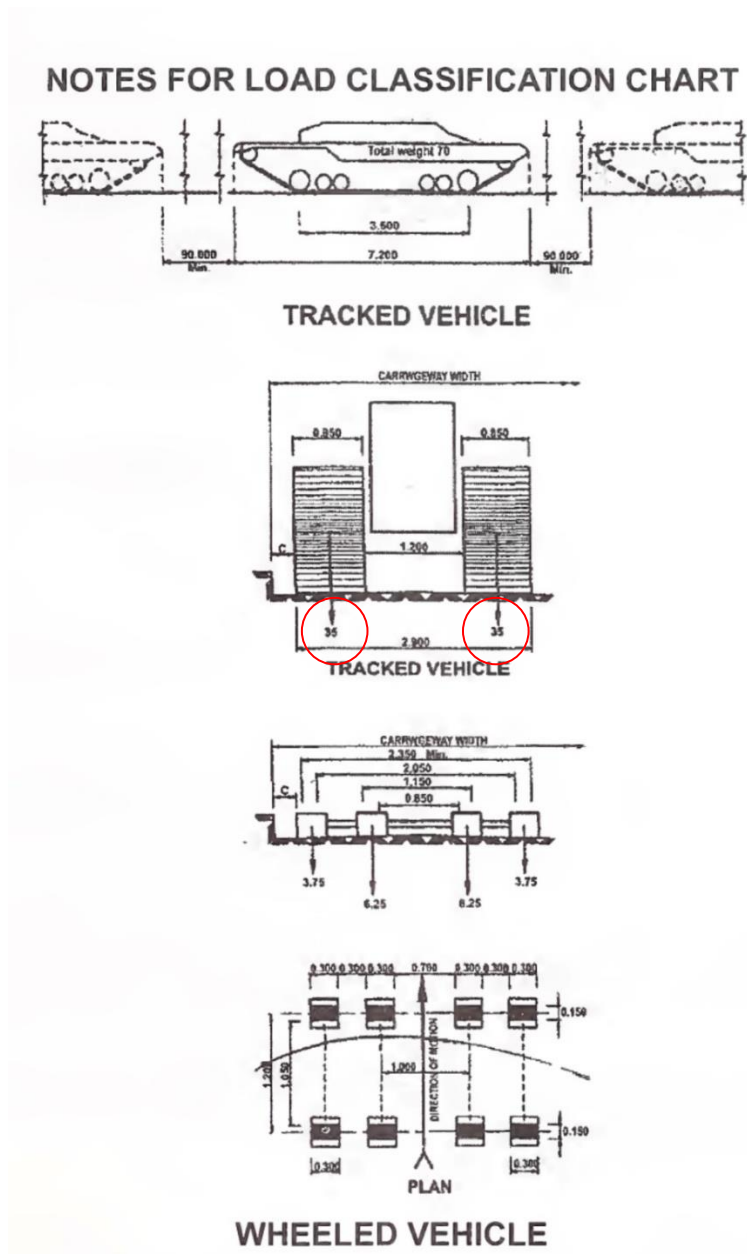


Figure 5 Class AA Tracked and wheeled vehicle load

3.3 Reinforcement Calculation:

3.3.1 Longitudinal Reinforcement:

Required Reinforcement percentage is calculated in Staad.Pro for control model.

Dead load and Live Load is applied on control model with one end fixed and other end pinned condition. As an output Staad.Pro gives Percentage of Reinforcement 0.05%.

But, as per **IRC 112**, in circular bridge pier minimum 1% percentage of reinforcement is required.

So as per this clause, we've provided 1% of reinforcement (P_t) [12].

So, Required Area of reinforcement,

$$\begin{aligned}
 A_{st} &= P_t / 100 \times \pi / 4 \times D^2 \\
 &= 1 / 100 \times \pi / 4 \times 5^2 \\
 A_{st} &= 0.19635 \text{ m}^2 = 19.63 \text{ m}^2
 \end{aligned}$$

Diameter of Reinforcement = 40 mm

$$\begin{aligned} \text{Area of 40 mm diameter reinforcement } (a_{st}) &= \pi/4 \times (40)^2 \\ &= 1256.64 \text{ mm}^2 \end{aligned}$$

$$\begin{aligned} \text{No. of longitudinal reinforcement} &= A_{st} / a_{st} \\ &= 196300 / 1256 \\ &= \mathbf{158 \text{ Nos}} \end{aligned}$$

So, In control model 158 no. of 40mm Diameter reinforcement should require (i.e. 1% of its cross sectional area.)

3.3.2 Transverse reinforcement.

As per IRC : 112 2011, clause 16.2.3 (2) The diameter of the transverse reinforcement shall not be less than 8 mm or one quarter of the maximum diameter of the longitudinal bar, whichever is greater.

In our model diameter of stirrups not less than $40/4 = 10\text{mm}$

We have consider diameter of stirrup = **16 mm**

3.4 Reinforcement Detailing In Control Model:

3.4.1 Longitudinal reinforcement.

When placing 158no. Of 40 mm diameter reinforcement circularly in one layer, spacing between two bars comes as approx. 95 mm which is very less and it is not fulfill IRC: 112 recommendation for longitudinal reinforcement minimum spacing.

As per IRC: 112 clause 15.2.1 the spacing between two longitudinal bars shall be more than 1) largest diameter bar, 2) $d_g + 10\text{mm}$ ($d_g =$ aggregate size) or, 3) 110mm whichever is more. In our case we shall take more than 110 mm spacing between two bars. [12]

To fulfill this requirement of spacing we've separated longitudinal bars in two half and placed circularly in bridge pier with alternate spacing with two layer. By placing reinforcement in this position spacing between bars comes as **190mm** and it is more than 110 mm. below figure shows placing of reinforcement in alternate position.

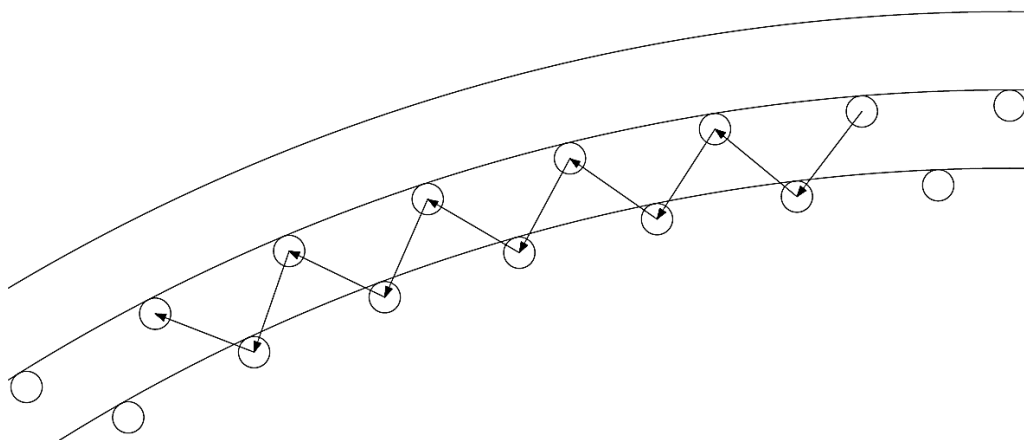


Figure 6 Alternate placing of longitudinal reinforcement

3.4.2 Transverse reinforcement:

As Per IRC 112: clause 16.2.3 (4) the spacing of the transverse reinforcement along the column axis shall not exceed the lesser of the following:

- 2 times the minim.um diameter of the longitudinal bars. ($2 \times 40 = 80$)
- The least dimension of the column (5000 mm)
- 200 mm

So, we have provided stirrups spacing = 300 mm

3.4.3 Reinforcement Detailing in Control Model:

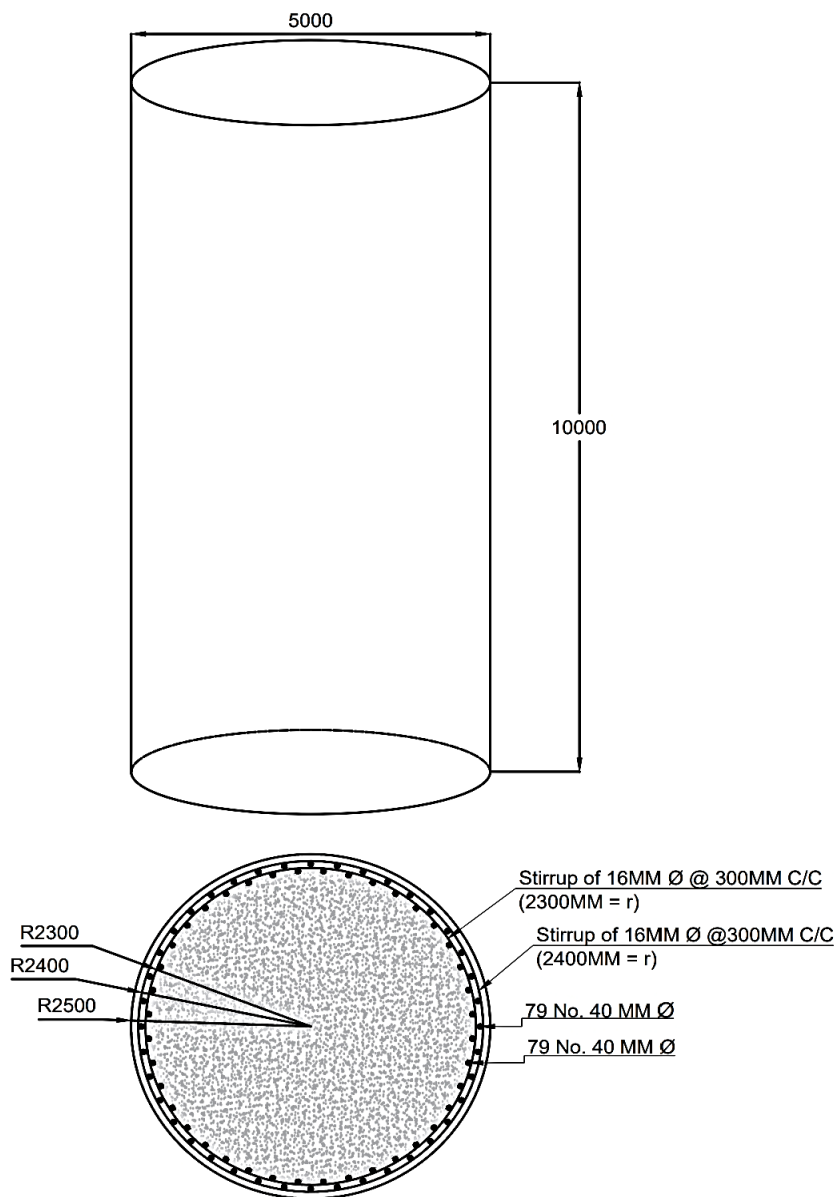


Figure 7 Reinforcement Detailing of Control Model

3.4.4 Reinforcement Detailing Slotted Bridge Pier:

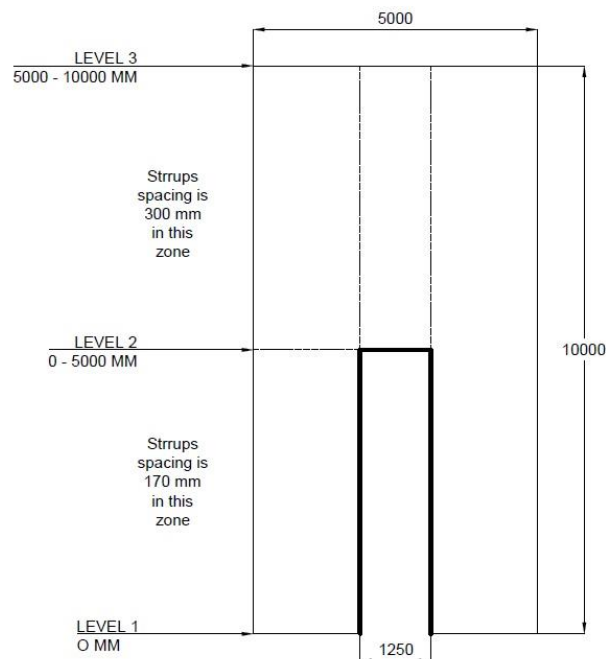


Figure 9 Level of slotted Bridge Pier

In slotted Bridge pier, from Level 1 to Level 2 (i.e., Up to 5 m height) act as a two columns in our case. Slot may place between this two columns. The longitudinal reinforcement of this two columns will continue till Level 1 to Level 3 (i.e., up to 10m Height). In this two column at 5 m height stirrups spacing may consider as 170 mm and above 5 m – 10 m stirrups spacing increases to 300 mm. because when loads are applied on this slotted bridge pier the bottom portion Up to Level 2 may show higher deflection zone i.e., hinge is created at that portion only. The behavior of Slotted Bridge Pier with No reinforcement condition showing in below figure.

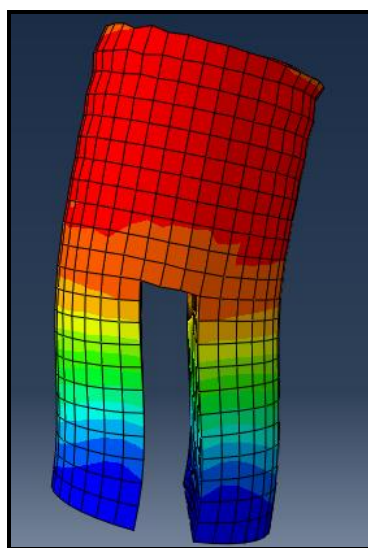


Figure 10 Behavior of slotted bridge pier Under No reinforcement condition

3.4.5 Reinforcement detailing from L1 to L2:

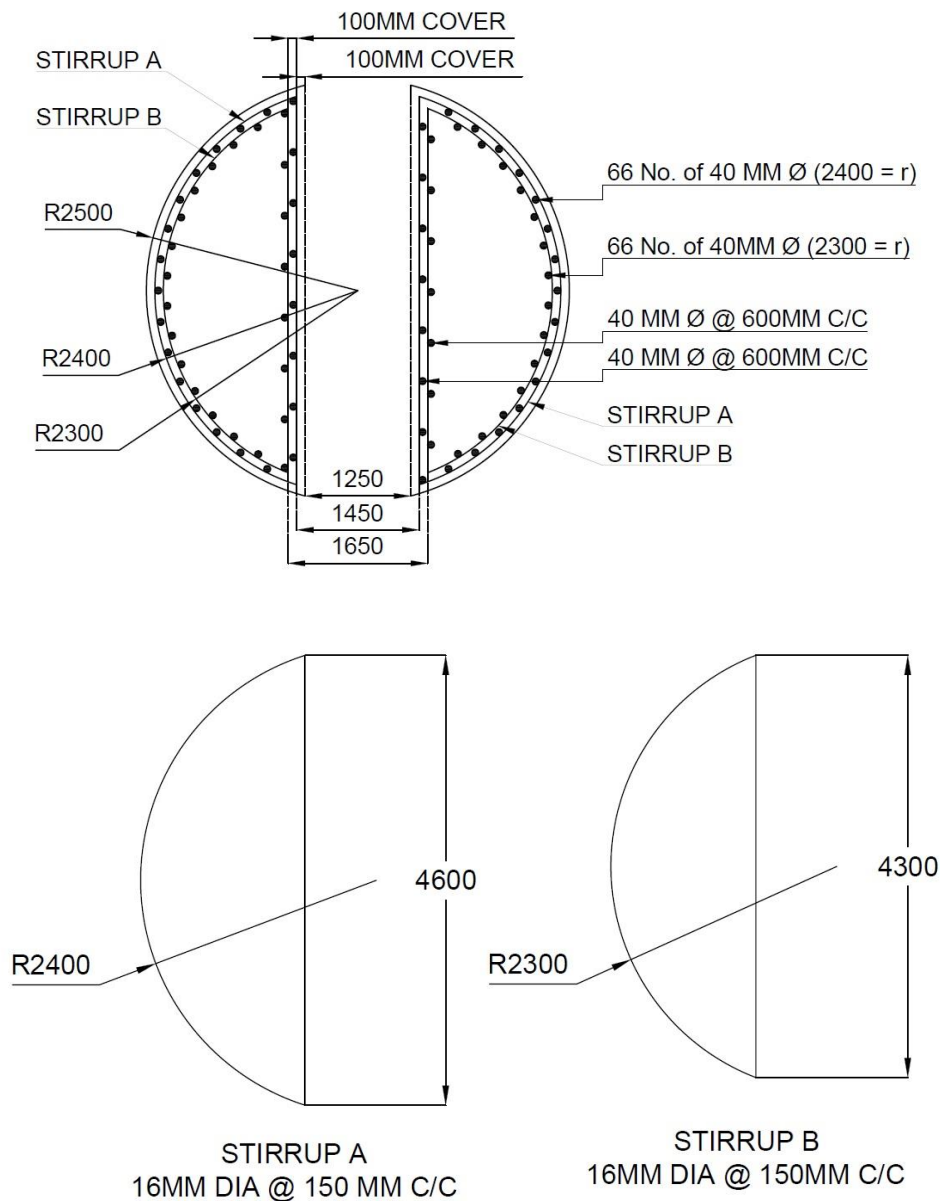


Figure 11 Reinforcement Detailing of Slotted Bridge Pier (Level 1 to Level 2)

3.4.6 Reinforcement Detailing at Level 2:

• Slab Detailing:

On top of slot, concrete weight comes, to take concrete weight we've created slab portion at the top of slot. Slab reinforcement is connected with longitudinal reinforcement which is running from L1 to L3. This slab act as one-way slab that's why the more reinforcements are provided along shorter direction. Again this reinforcement diameter is 40 mm, and spacing between reinforcement taken as 600 mm.

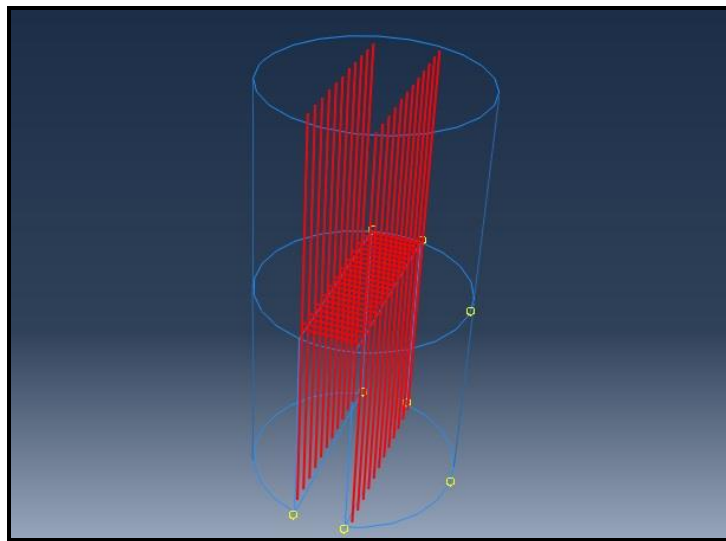


Figure 12 Render Image of Slab reinforcement on top of Slot

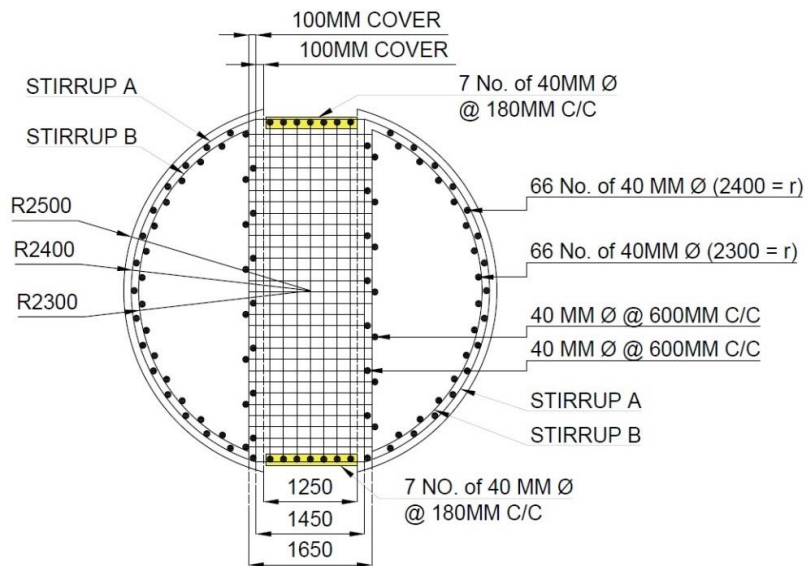


Figure 13 Reinforcement Detailing of SBP at Level 2

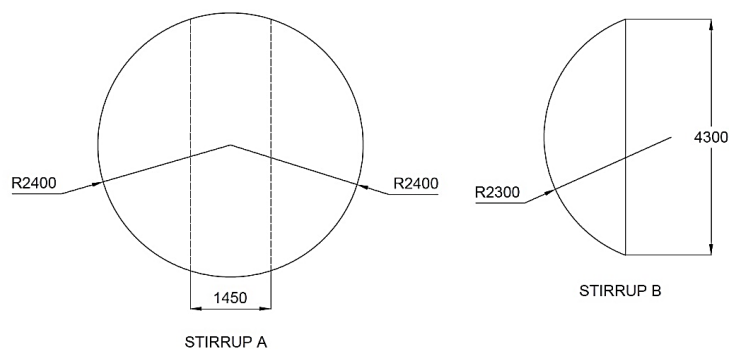


Figure 14 Stirrups Detailing at Level 2

Now as given in figure 11, yellow highlighted reinforcement portion is placed in longitudinal direction on top of slot which act as distribution bar. Its diameter is also 40 mm and spacing between reinforcements is kept as 180mm c/c.

At level 2 to level 3 slot is no more exist, to fill that portion with reinforcement we've provided longitudinal reinforcement. Again this longitudinal reinforcement are continues with the distribution reinforcement of slab. Which will format 'C' Shape reinforcement detailed. Whole phenomenon given in below render figure below, so that whole thing may get clear.

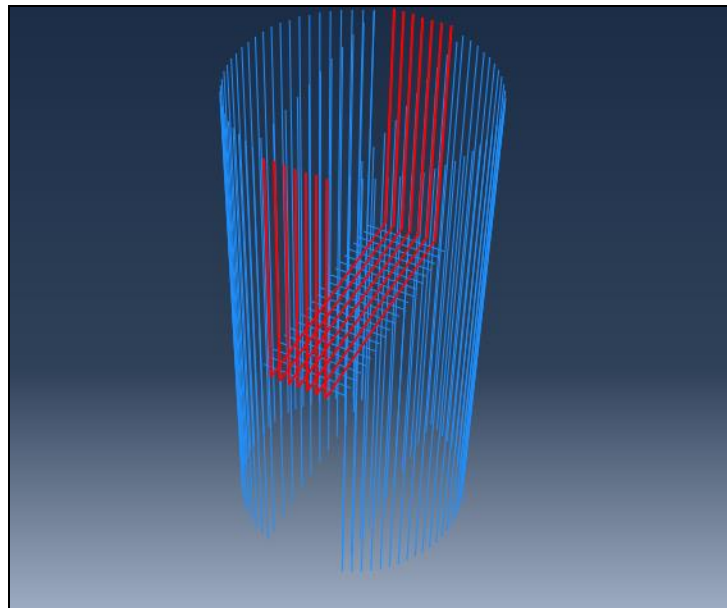


Figure 15 'C' Shape reinforcement detailing

Highlighted reinforcements are in shape 'C', in which horizontal reinforcement is tie-up with slab reinforcements and reinforcement along height is again tie-up with stirrups that used in to tie-up reinforcement along periphery of the pier (ref. figure : 13, Stirrup A).

Here one thing that I would like to clear that, the reinforcements beside slot are also in two layer both side which is in alternate pattern with each other. Which means the right side reinforcements which is in two layer and each layer reinforcement is alternate. Now left side reinforcements are also in two layer and each layer reinforcement is alternate. And this right side and left side reinforcements in alternate to each other. Main reason to do this pattern is that no reinforcement get clash to each other. For better understanding show given figure below.

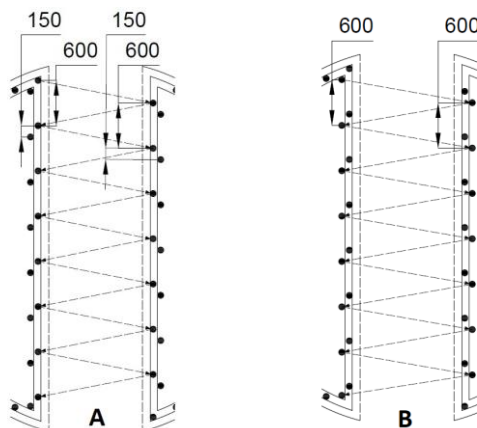


Figure 16 Alternate pattern in reinforcement beside slot (A) outer layer reinforcement (B) Inner layer Reinforcement

Inner side reinforcements are running throughout the height of pier (10 m) and horizontal reinforcements are tie-up with the longitudinal reinforcement. When in case of outer side reinforcement, it is not to the end of pier, it is just at a slot height (5.1 m, where 5 m slot height and 100mm cover). the reason behind the outer side slot reinforcement of height taken similar of slot height is to reduced reinforcement percentage and second reason that is inner side reinforcement running throughout height of pier is because if it is not running throughout the height of pier than how stirrups can tie-up the inner layer reinforcement over periphery of the SBP.

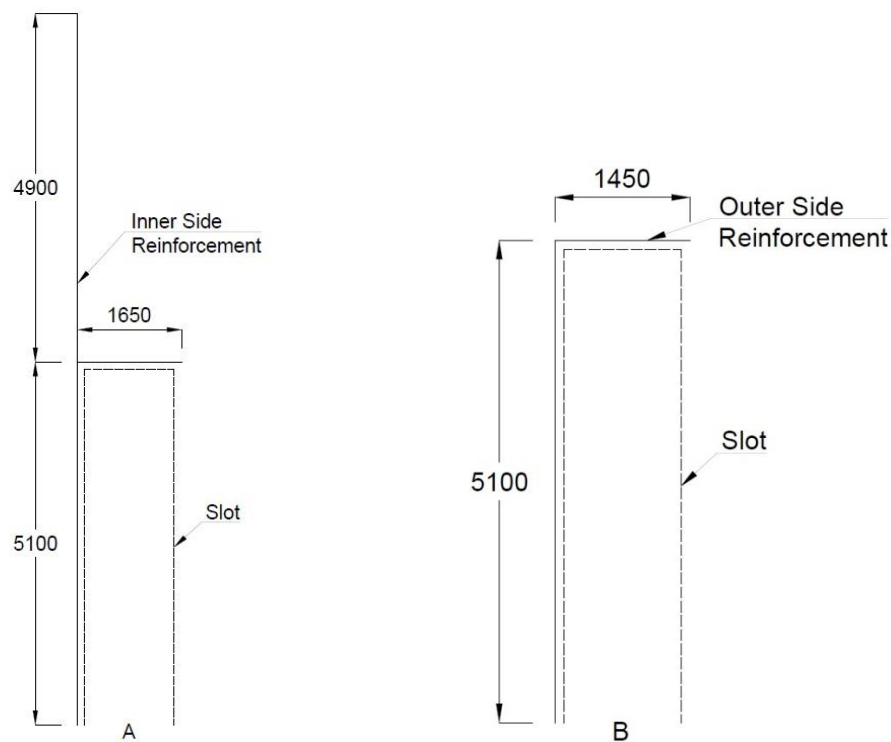
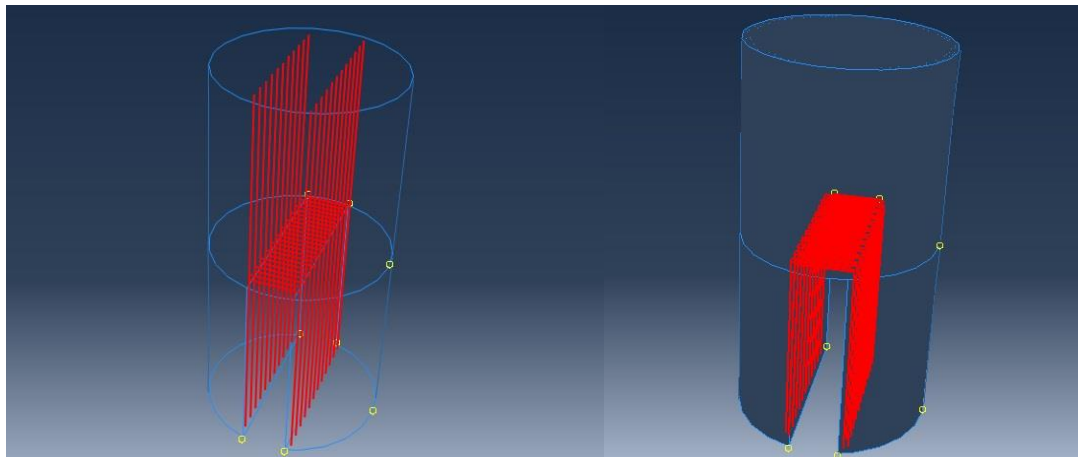


Figure 17 (A) Inner side reinforcement shape (B) Outer side reinforcement shape

3.4.7 Reinforcement Detailing at Level 3:

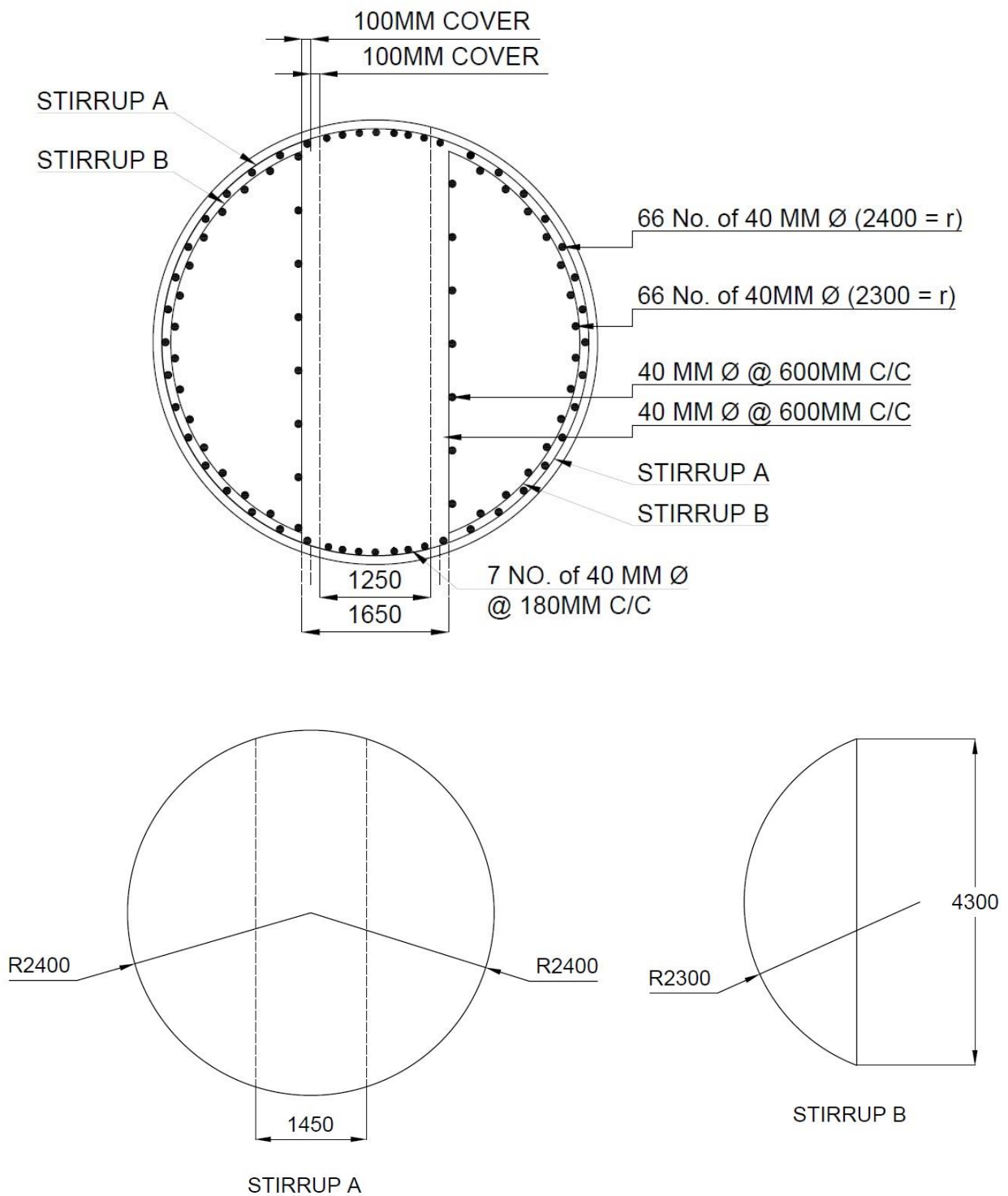


Figure 18 Cross of section at Level 3

4. RESULT SUMMARY

4.1 Control Model result summary

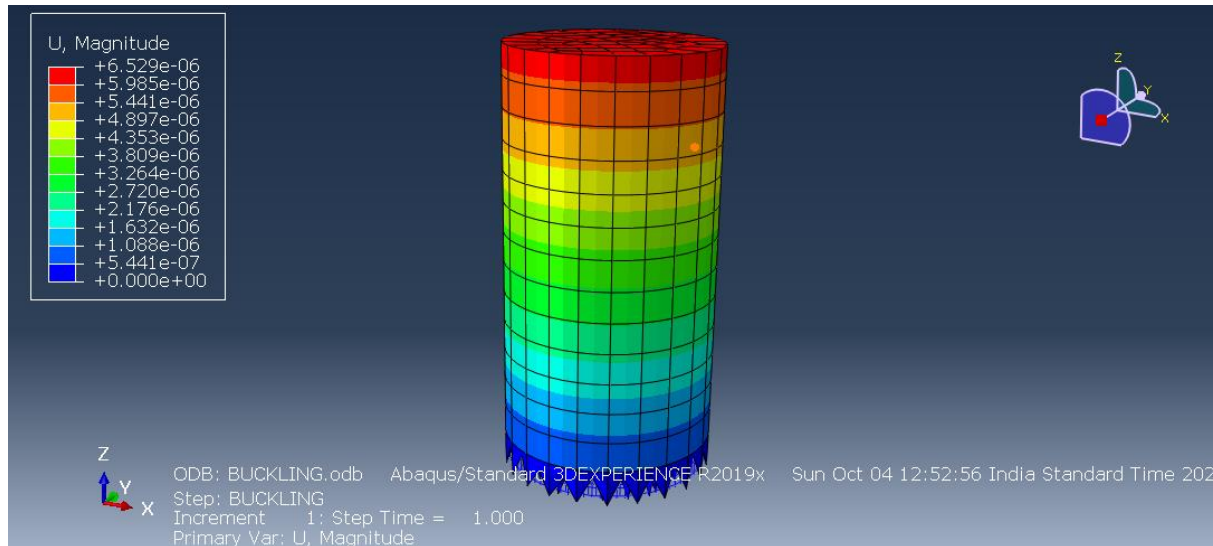


Figure 19 Control Model Output

1. As you can see in output results, U stands for Displacement. Maximum displacement occurs at the top of pier and it is quite obvious that effect of applied loads are maximum at that portion.
2. The value of displacement comes as $+6.529 \times 10^{-6}$ which is almost tends to '0'.
3. So we can say the control model is safe against applied loads. Which maximum as per IRC. We also have detailed the pier as per IRC recommendation so it is also safe against the applied load.

4.2 Slotted Bridge Pier result summary

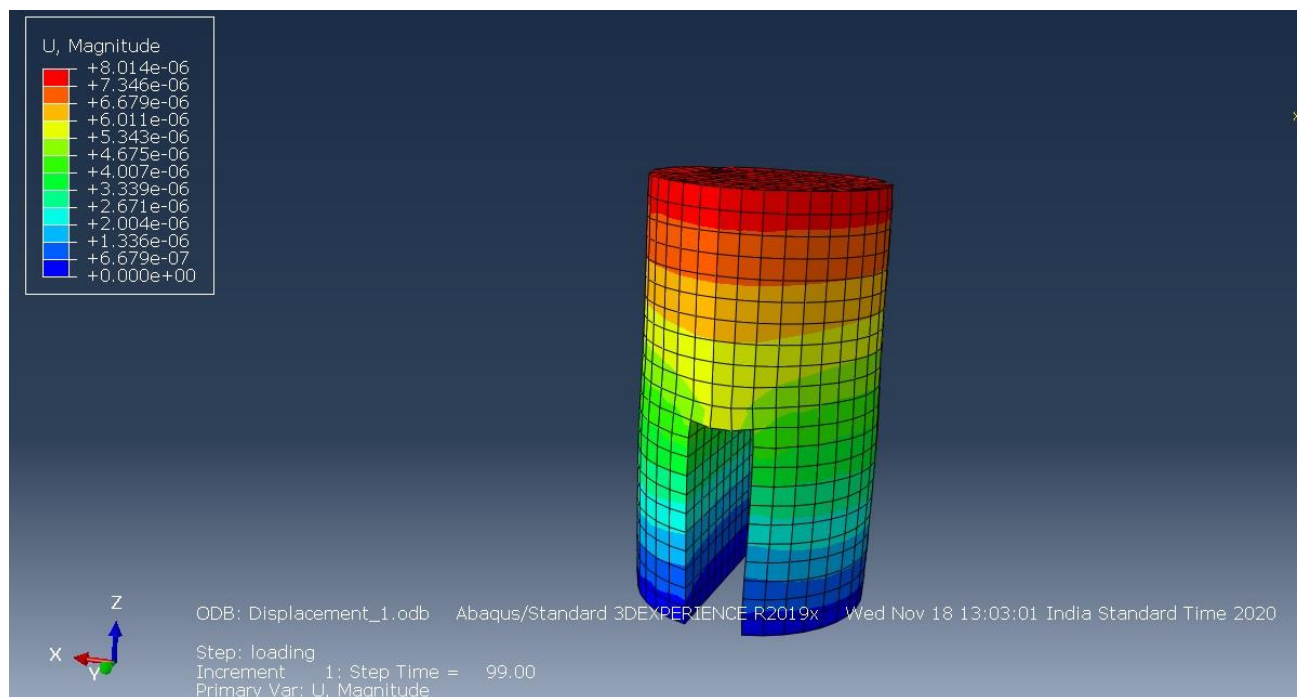


Figure 20 Slotted Bridge Pier Output

1. Maximum displacement in slotted Bridge Pier occurs at the top of pier and here also the same thing happen as control model that effect of applied loads are maximum at that portion.
2. In SBP, column 1 and 2 are main key component because on these slab is rested and self-weight of concrete above the slot is concentrated over this portion only. The main noticeable thing is that they are neither buckled nor does any noticeable displacement occur. So we can say it is safe against applied loads. Maximum displacement occurs at top and at a center the value of displacement up to $4.00 * 10^{-6}$ which is less as compare to top displacement.
3. Second observation we need to take is stability of slab. As per outcome it is clear that slab is also safe and displacement on slab is also up to $4.67 * 10^{-6}$

5. CONCLUSIONS

- 1) Maximum displacement occurs at top of pier which is almost "0" and also same as compare to control model.
- 2) It also Prove that the amount of reinforcement used in control model is almost same amount of reinforcement used in slotted Bridge Pier and there is no any riddle occurs.
- 3) To get above conclusion it is necessary, whatever reinforcement pattern used in Slotted Bridge Pier is in correct manner and it is able to with stand against applied loads.
- 4) In slotted Bridge Pier it is necessary to provide reinforcement detailing which act as column on both the side of slot and it must be running throughout the total height of pier.
- 5) In this column reinforcement detailing, the spacing of stirrups is kept less up to the height of the slot then it may increase.
- 6) To restrain the weight of concrete over slot it is also necessary to provide slab over slot. Slab can take an excessive weight of concrete over slot.
- 7) Slab reinforcement are must be tie-up in correct manner with longitudinal reinforcement which are running through the height of pier.
- 8) Slab reinforcement along shorter direction act as main reinforcement and reinforcement against longer direction act as secondary reinforcement.
- 9) If we used slotted Bridge Pier than other option it is economical. When we provide slot in between bridge pier, The Volume of concrete for the slot is deducted, and the saving in concrete. We have used almost same amount of reinforcement in SBP as used in control model. So we can say no other reinforcement required.

REFERENCES

- [1] B. M. Sreedhara1, Manu Rao1, Sukomal Mandal , "Application of an evolutionary technique (PSO–SVM) and ANFIS in clear-water scour depth prediction around bridge piers", The Natural Computing Applications Forum (2018)
- [2] Yee-Meng Chiew, Member, ASCE, "Scour protection at bridge piers", Journal of Hydraulic Engineering. (1992)
- [3] Ali Khodabakshi, Mojtaba Saneie, Abdolnabi Abdoh Kolahchi "Experimental study on effect of slot level on local scour around bridge pier" International Journal of Research in Engineering and Technology (2014)
- [4] Mehdi Osroush , Seyed Abbas Hosseini, Amir Abbas Kamanbedast, Amir Khosrojerdi, "The effects of height and vertical position of slot on the reduction of scour hole depth around bridge abutments" Ain Shams Engineering Journal (2019)
- [5] Viren kumar, Kittur G. Ranga Raju, and Nandana Vittal "Reduction of loacal scour around bridge piers using slots and collars" Journal of hydraulic engineering (1999)
- [6] A.T. Moncada, J. Aguirre , J.C. Bolívar, E.J. Flores "Scour protection of circular bridge piers with collars and slots", Journal of Hydraulic Research Vol. 47, No. 1 (2009), pp. 119–126
- [7] M. Heidarnejad, M. Shafai Bajestan, and A. Masjedi "The effect of slot on scoring around piers in different position of 180 degrees bends", World Applied Sciences Journal 8 (7): (2010)
- [8] Hooman Hajikandi, Mahsa Golnabi, "Y-shaped and T-shaped slots in river bridge piers as scour countermeasures", ICE Publishing (2016)
- [9] Manouchehr HEIDARPOUR, Hossein AFZALIMEHR and Elham IZADINIA , "Reduction of local scour around bridge pier groups using collars", International Journal of Sediment Research 25 (2010) 411-422
- [10] Tafarojnoruz, R. Gaudio & F. Calomino, "Effect of a slotted bridge pier on the approach flow", conference paper 2012 research gate
- [11] IRC: 6-2014 "standard specifications and loads of practice and code of practive for road bridges", "section 2 Loads and stresses".
- [12] IRC:112-2011 "Code of practice for concrete road bridges