DESIGN AND ANALYSIS OF STILLING BASIN TRAINING WALL WITH CANTI LEVER RELIEF SHELVES

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ABSTRACT

Side training walls are provided for stilling basin. But sites, where space constraint is there, gravity wall cannot be provided. Hence, a special type of training wall has been envisaged which has cantilever relief shelf on the earth retaining side. The concept of providing pressure relief shelf on the backfill side of a retaining wall reduces the total earth pressure on the wall, which in turns reduces the overturning moment. This type of training wall has been conceptualized and designed analytically as well as using FEM (Finite Element Method) software ANSYS considering all the prevailing forces in dynamic case for partially submerged backfill condition. Moments and Stresses are corroborated with both the analysis and used for optimized design. Length of cantilever relief shelf and gap between multiple relief shelves is optimized for various conditions. Stilling basin floor slab also acts as the toe side of the base of cantilever retaining wall which helps in improving FOS and bearing. Comparison for Factor of safety (FOS) for sliding and overturning with varying numbers of relief shelf has been drawn.

1. INTRODUCTION

A training wall is needed at the downstream of the dam to guide the water, as well as a stilling basin has to be provided to dissipate the water forces arising from spillway discharge. The bank at the downstream end is weak and susceptible to erosion. A retaining cum training wall is needed to be provided which can improve the bank stability as well as guide the downstream water.

The present condition at the site requires to guide the water flowing up to height of 25m as well as to protect the bank of the side slope. If gravity retaining wall is provided, the base width required at bottom of wall would be very large which further would require cutting the bank slope. Hence the possibility of cantilever retaining wall (CRW) is envisaged. But providing a 25m high CRW was difficult as stresses at the bottom would be too much.

A special type of CRW with pressure releasing relief shelves is proposed. CRW with relief shelves is a particular type in which the shelves are protruding out on the backfill side all throughout the length. These relief shelves are constructed monolithically with the stem of the retaining wall. These protruding shelves are extended such that they cut the lateral pressure triangle in multiple parts. Following the Rankine's earth pressure theory, the lateral pressure is exerted by the equivalent mass in the failure wedge. Hence, these multiple shelves which divide the failure wedge in multiple parts, in turn make the one continuous pressure triangle into multiple small one.

Moreover, the shelves provide the stabilizing moment due to gravity load on them. Thus, not only these reduce the overall lateral forces but improve the overturning stability. The reduction in lateral forces reduces the thickness requirement of stem of the retaining wall. This greatly helps where space constraint is an issue.

Loading Conditions are considered as per the site requirements. Dynamic load considerations have been taken for submerged condition. Five combination of the retaining wall have been analyzed and compared with the same type of loading conditions. These five combination are namely CRW without any relief shelf, CRW with 4 relief shelves, CRW with 5 relief shelves, CRW with 6 relief shelves and CRW with 7relief shelves.

Overall structure stability has been analyzed using equilibrium theory/limit state analysis and for parts of structure FEM (finite element method) has been adopted. The idea behind using FEM for the analysis of structural parts is that it gives better picture of the impact of relief shelves in its vicinity apart from its impact on overall structure. For FEM analysis ANSYS 15.0 has been used.

2. LITERATURE REVIEW

Jumikis(1964) studied the effect of adding relief shelves to a counterfort wall to increase the stability of the wall and found that relief shelves decrease the lateral earth pressure and increase the overall stability of retaining structure.

Yakovlev(1964-1975) studied earth pressure distribution on a wall with two relief shelves and found that when the wall was permitted to move, an internal sliding surface gets developed from the end of the shelf. This surface is formed in the backfill zone above the shelf. The study also correlated the position of the internal and external sliding surfaces and the width along with embedded depth of the shelf. For the same embedded depths of a shelf, the dimensions of the sliding zone increase with increasing platform width.

Klein(1964) discussed a distribution for the earth pressure above and under the shelf. His distribution is approximately compatible with the measurements of Yakovlev. This study defined a sloped transition line using two defined points. It can be observed that there are two distributions: (a) for the shelf that is not extended to the rupture line and (b) for the shelf that is extended to the rupture line.

Shravya et al (2012) discussed that retaining wall with relief shelf platform provides most economical design for wall heights where CRW is not a feasible option.

Hany F. Shehata (2016) conducted a parametric study to investigate the effectiveness of the shelf rigidity and the shelf position on the lateral earth pressure distribution, top movement of the wall, and maximum bending moment. The study founded that by providing the CRW with a single shelf at a depth ratio (h1/H) of 0.30 and shelf width is extended to the rupture surface results in a decreased bending moment of approximately 30 % of its cantilever value. The solution of Klein and the measurements by Yakovlev are in good agreement with the results of the FEM. Updates are provided to Klein's solution for the acting maximum bending moment of the wall to enhance the results to be more logical and to agree with the FEM solution. Where h1 is the location of first relief shelf from top and H is total height of CRW.

Liu et al (2018) established a model of the earth pressure on retaining wall with relieve platform. According to their study, the size and position of relief shelf platform affect the overall earth pressure acting on the wall. The maximum reduction in earth pressure was found when the gap between the relief shelves was equally distributed.

3. METHODOLOGY

According to the Rankine's theory of earth pressure, the pressure due to backfill in active condition is exerted in accordance with the failure wedge. And this failure wedge plane is assumed to be making an angle of 45 + (ϕ/2) degree whereas for passive case an angle of 45 - (ϕ/2) with the horizontal line. The lateral pressure due to backfill on the wall is calculated as per Rankine's failure wedge which is the multiplication of active/ passive coefficient and vertical pressure at any depth from top.

If inclination of top of backfill with horizontal is greater than 0^o, then angle of failure wedge for active case is given by:-

$$45 + (\varphi/2) + (\beta/2) - \frac{1}{2}\left[\sin^{-1}\left(\frac{\sin\beta}{\sin\varphi}\right)\right] \qquad (1)$$

Whereas for passive case it is given by:-

$$45 - (\varphi/2) + (\beta/2) + \frac{1}{2}\left[\sin^{-1}\left(\frac{\sin\beta}{\sin\varphi}\right)\right] \qquad (2)$$

Where φ is the soil friction angle and β is angle of inclination of top of backfill with horizontal. As per the site condition we have taken φ as 34° and β as 30°.

As per equation 1, failure wedge angle is calculated 45.3° for the worst condition as shown in Fig. 1.The conclusion made by Klein and Liu et al the length of the relief shelf would be such that, it cuts the failure wedge plane angle at 45.3° from horizontal and gap between the relief shelves is maintained equally distributed as shown in Fig.1. Length of relief shelf depends on gap between relief shelves and failure wedge angle. Keeping the failure wedge angle constant, by varying number of relief shelf and maintaining equal gap, length of relief shelf is calculated. For failure wedge angle 45.3^o, length of relief shelf is calculated as shown in Table 1.

Table 1 : Length of relief shelf for varying gap and numbers of relief shelves

Sr. No	Number of relief shelves	Clear gap between relief shelves in meter	Length of relief shelf in meter
1	4	6m	6m
2	5	5m	5m
3	6	4m	4m
4	7	3.5m	3.5m

The thickness of stilling basin was coming out to be 7m as per the site requirement to make it safe against uplift pressure. The retaining wall needed extended length of the base to dissipate the pressure due to vertical load. As base of retaining wall on hill side (backfill side) cannot be extended due to space constraint, so it is imperative to extend the base on the toe side (water side) which will not only be a part of retaining wall but also be a part of stilling basin with same thickness. Moreover, advantage for providing such arrangement is that, additionally it provides safety in sliding for the retaining wall. Hence, 10m of the stilling basin raft of thickness 7m will be part of stilling basin base too with needed reinforcement as per the requirement of retaining wall. After 10m, the construction joint will be provided then regular stilling basin will follow across the flow. A general outline of such arrangement has been shown in Fig. 2

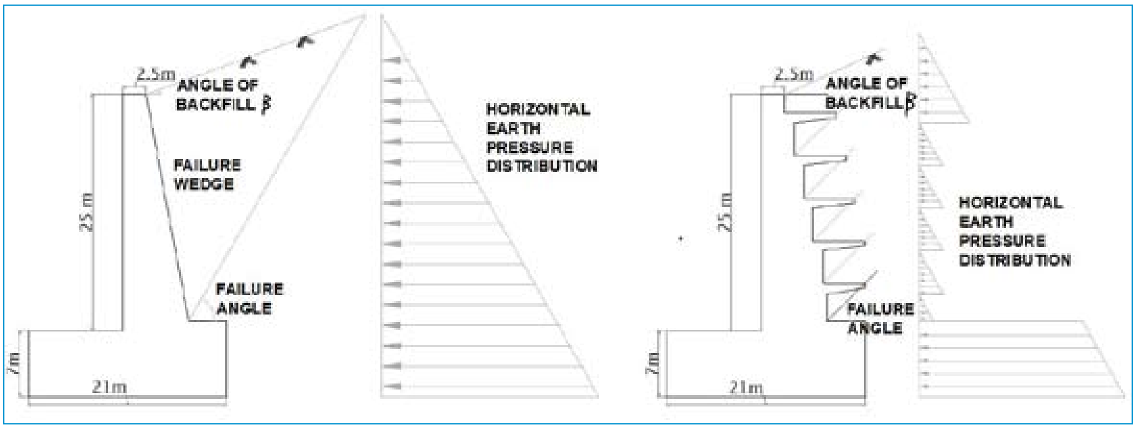

Figure 1 : Horizontal earth pressure variation

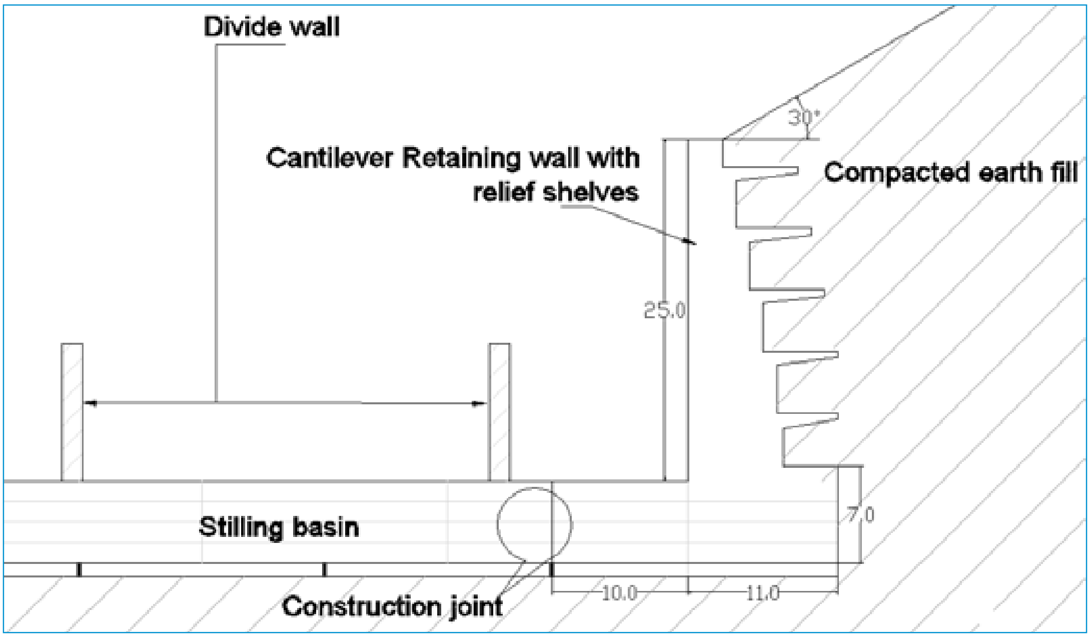

Figure 2 : Arrangement of CRW with relief shelves and stilling basin

According to the guidelines laid by IS 1893: Part I (2002), as per the site condition, the static and dynamic coefficient for lateral earth pressure has been calculated to be 0.478 and 0.810 respectively.

Parameters considered for the analytical design as well as FEM using ANSYS are listed in Table: 2

Table 2 : Parameters adopted for analytical and FEM analysis

Sr. No.	Parameters	Value
1.	Grade of concrete **(f_{ck})**	25 MPa
2.	Unit wt. of concrete **(Υ_c)**	24 KN/m^3
3.	Cohesion of backfill material **(C)**	0 KPa
4.	Angle of repose of backfill material **(φ)**	34^o
5.	Saturated unit wt. of backfill material **(Υ_{sat})**	23.5 KN/m^3
6.	Submerged unit wt. of backfill material **(Υ_{sub})**	13.5 KN/m^3
7.	Unit wt. of backfill material at natural moisture content **(Υ)**	21 KN/m^3
8.	Angle of top of backfill **(β)**	30^o
9.	Unit wt. of water **(Υ_w)**	10 KN/m^3

3.1 Loading considerations

Water table considered to be at 12.5m from top of CRW (i.e. half of the wall height) to account for the submerged condition. Lateral soil load on stem *between two relief shelves*is taken as per individual pressure triangles as shown in Fig 1. Whereas the lateral soil load *on the edge of relief shelf* is taken to be from top of the filling. Water load laterally is considered separately from 12.5m depth to 25m depth. Vertical soil load is considered to act on every relief shelf as per the gap between two relief shelves.

3.2 Analysis and Comparison

After applying the loads, as per the site conditions, stability of the overall structure has been analytically computed in dynamic case and compared for the five combinations mentioned above. Analytical method has been used for calculation of factor of safety of structure in sliding and overturning and total lateral forces exerted by soil and water on stem part of the wall.

3.2.1 *Analytical analysis*

Analytical analysis has been carried and following interpretation of variation of vertical loads, horizontal loads, bending moment, shears force and overall factor of safety shown in Table 3.

Table 3 : Analytical analysis-loads and results

Dimension					
Nos. of Relief shelves	0	4	5	6	7
Length of Relief shelves in m	0	5.5	4.5	4	3.5
Spacing between relief shelves in m	0	4.5	3.5	3	2.5
Loads considered (Dynamic Case)					
Vertical load (Dead wt.+ soil wt.) in kN/m	10060	10297	10292	10278	10259
Horizontal load (Soil load +Water load) in kN/m	8449	5249	4679	4575	4335
Results(Dynamic Case)					
Factor of Safety(FOS) in Sliding	0.36	0.68	0.75	0.71	0.72
Factor of Safety(FOS)in Overturning	0.96	2.28	2.22	2.04	2.00

As seen in Table 3,In case of CRW with relief shelves, the total vertical load is more than the CRW with no relief shelf, as the former includes additionally the weight of relief shelvesprotruding in the backfill side. As the vertical load increases the Factor of safety in overturning and sliding of CRW also increases.

The main objective of providing the relief shelves is to divide the lateral pressure triangle into multiple one. The total horizontal load on stem has been reduced by 38% to 49%after increasing the number of relief shelves from 4 to 7.

There is also increase in factor of safety (FOS) of the structure by adding the relief shelves. As shown in Table 3, FOS against overturning increases from 0.96 to 2.00 and FOS against sliding increases from 0.36 to 0.72 as the relief shelvesare included. However, the minimum factor of safety in sliding as per IS: 456 2000 should be greater than 1.4. But as the CRW base is being resisted by stilling basin floor, which provides sufficient resistance against sliding by directly transferring the horizontal force to the left side bank. The compressive stresses are within the permissible limits when this thrust is being taken by stilling basin floor. Hence, the structure will always be safe in sliding.

3.2.2 *Finite element method*

Similarly, finite element method using ANSYS has been used to compute tensile and compressive stresses in horizontal and vertical direction, shear stresses, deflection of the structure in dynamic case. While using ANSYS, a foundation of 3Bx1.5B dimension has also been incorporated to foresee the impact and stress distribution of the retaining wall in the foundation (B = width of retaining wall at base).

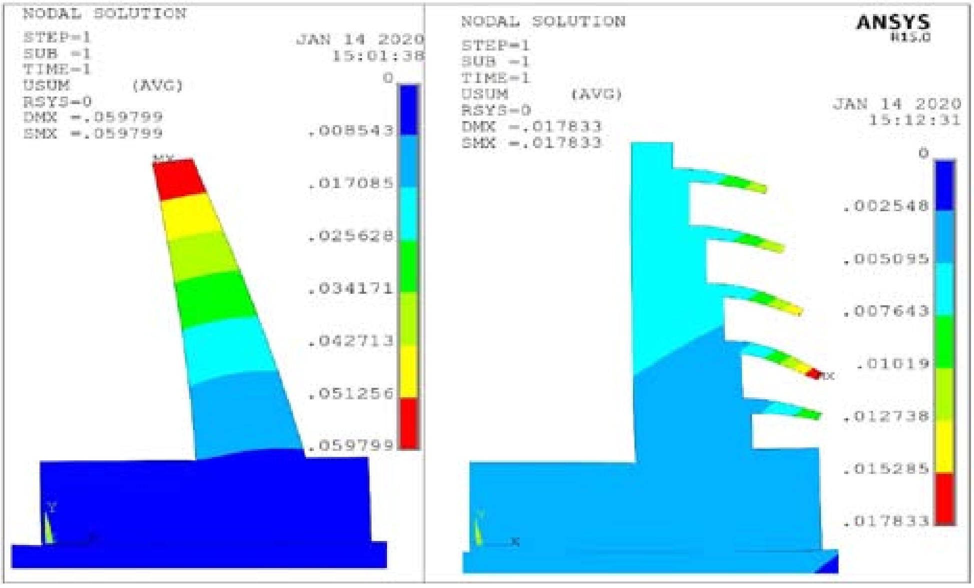

Figure 3: Deflection (m) Variation in the section (Dynamic case)

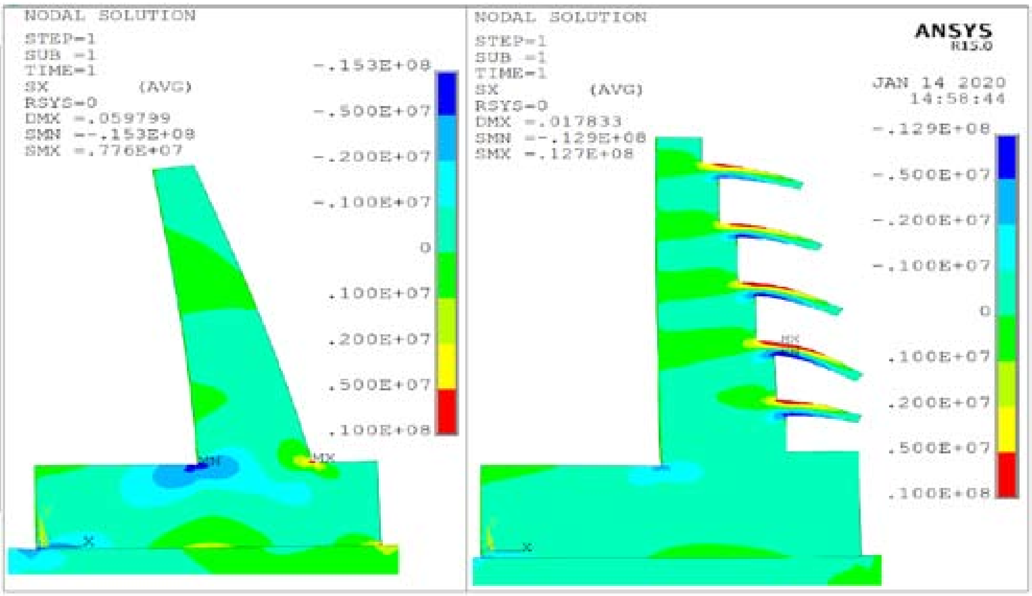

Figure 4 : Stress(Pa) in X-direction in retaining wall with and without relief shelves(Dynamic case)

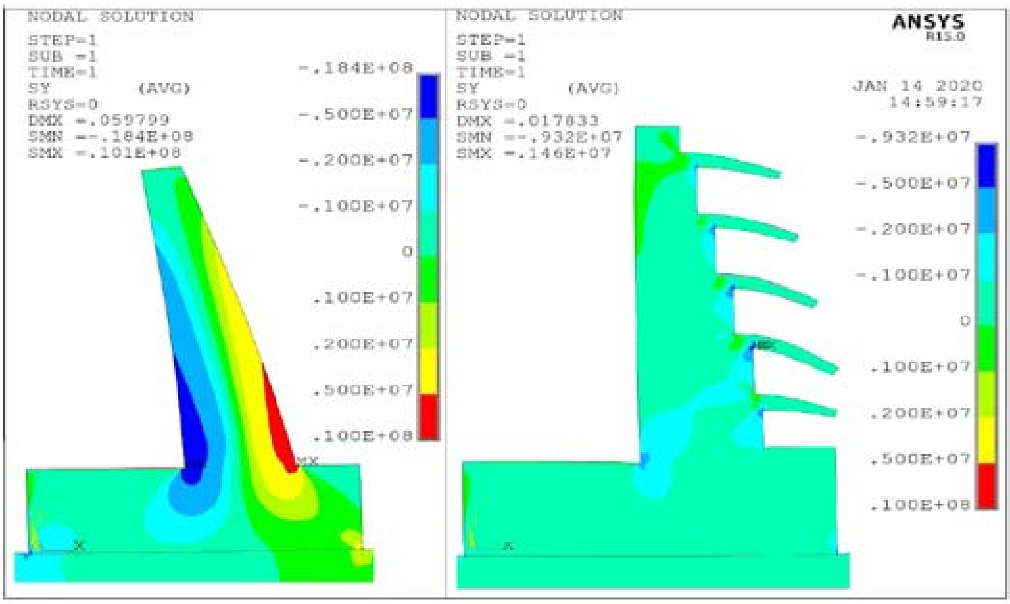

Figure 5 : Stress (Pa) in y-direction in retaining wall with and without relief shelves (Dynamic case)

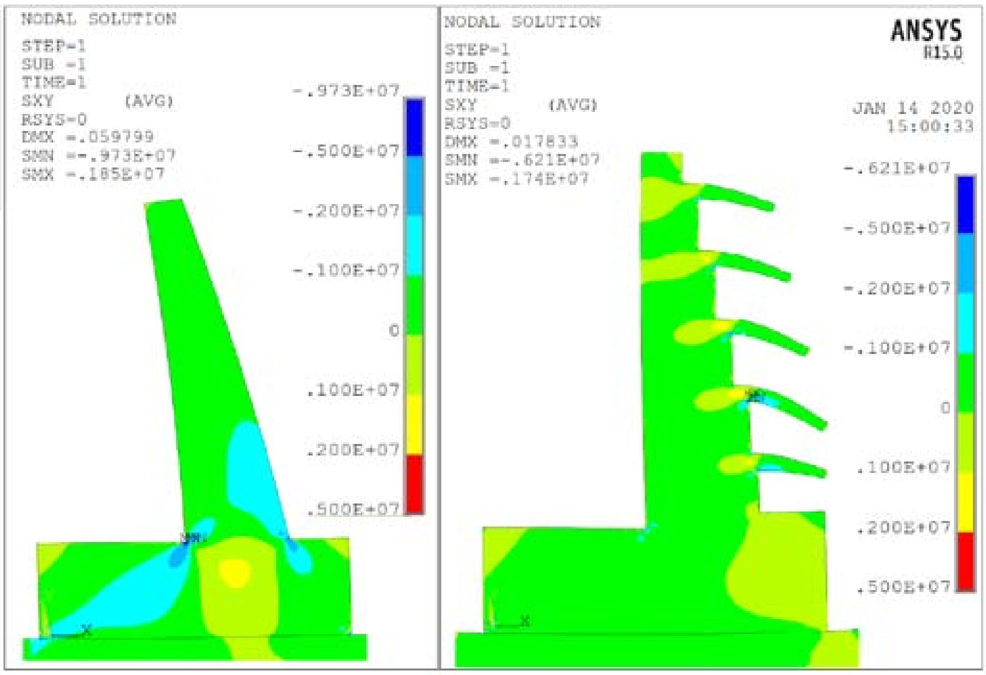

Figure 6 : Shear Stress (Pa) in retaining wall with and without relief shelves (Dynamic case)

Referring Fig.3, from the finite element analysis in ANSYS, it was found that displacement at the top of retaining wall without relief shelf is maximum. Further analysis on CRW with more number of relief shelvesit was found that when the number of shelvesis increased more than 5, there is again increase in displacement, although it is still very less compared to the displacement in wall with no relief shelf. The reason being, CRW with less relief shelveshas more gap between two relief shelves and has longer width/length of relief shelf as compared to others, therefore, it encompasses more vertical soil load, which provides more stabilizing moment to the stem, hence less displacement at the top of the stem.

Referring Fig. 4,in the horizontal direction there is a localized tension being developed at the upper part of the stem of the CRW with no relief shelf, but when provided with relief shelves, this tension area gets distributed quite evenly from top to bottom height of the stem. Also the compression stress at the toe side of the stem gets drastically reduced from 15Mpa to 5MPa when comparing without relief shelf CRW and with CRW relief shelves. The tensile stress of 10MPa at the heel side also changes to compressive stress of the order of 1MPa. In the base of the CRW also there is shift of tensile stress to compress stress of 1MPa.

Referring Fig. 5, in the vertical direction there is compressive stress of 18.4MPa at toe side and tensile stress of 10MPa in CRW with no relief shelf. By adding up to 5 relief shelves, this stresses reduces to 5MPa at toe side and 2MPa at heel side both in compression. Increasing the relief shelf shelves beyond 5nos there is localized zone of tensile stress formed at heel side of the order of 1MPa.

Referring Fig.6, the shear stress at junction of base and stem decreases from 9.73MPa to 1MPa by adding the relief shelves.

4. CONCLUSION

The present study illustrates the impact of adding the relief shelves and increasing the number of shelves for a25 m height CRW. The loading conditions are as per the site requirements. Based on the variation in number of relief shelves attached to CRW and gap between them for a particular wedge failure angle as per the site condition, following conclusion have been drawn:

1. By providing the relief shelf behind the wall, there is increase in the stability of wall due to decrease in horizontal soil pressure.
2. The overturning bending moment about toe and shear stress at junction of base and stem reduces to half of the original value.
3. Localized stresses are now distributed evenly throughout the section. Also the stress magnitudes are reduced with in permissible value of M25 grade concrete.
4. The factor of safety of overall structure has been increased in overturning as well as in sliding.
5. For a particular section of a retaining wall, the horizontal pressure reduces up to a limit with increase in the number relief shelves. But as the number of relief shelves increases further, the gap between them decreases, therefore, the horizontal pressure on stem also increases, resembling to a behavior of a normal CRW with no relieves.

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