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Comparison between Stone Masonry and RCC Retaining Walls on Hill Roads

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Abstract. Hill road projects involve construction of retaining walls as an intrinsic part of almost each road project. In general, retaining walls of varying heights, are being implemented along valley side of hill roads to construct the carriageway. For heights up to 10.0m to 12.0m conventional RCC cantilever or gravity type retaining walls are proposed. Procurement and transportation of raw materials like cement, reinforcement, and fine aggregates are very difficult in high altitudes. In most of the cases construction of retaining walls are required to be start from deep valley and continued up the hill. Placing shuttering and reinforcement at such deep valley is of great challenge in case of RCC construction. Moreover, getting water for concreting is difficult at such high hills as locally available water, in most of the cases, are reach in minerals which may affect the durability of concrete. On the other hand, in hills, hard to defragmented rocks are easily available and thus stone masonry retaining walls are good alternatives here in place of RCC retaining walls. Some disadvantages are also associated with stone masonry retaining walls like very less capacity under flexure and tension which make these walls heavy which in turn attracts high seismic forces. This paper presents a comparison between RCC cantilever type wall and stone masonry gravity walls. A comparison has been done between the two types of walls for similar earth retention heights for parameters like base pressure requirement, factor of safety against stability, associated seismic force, and quantity.

Key Words: retaining wall; stone masonry; seismic on retaining wall; dynamic increment; of earth pressure; tensile stress; compressive stress; factor of safety.

1.INTRODUCTION

Design methodology of RCC retaining wall and stone masonry retaining walls are quite different. As per latest code provision, ultimate limit state design to be adopted for RCC structures whereas stone masonry retaining walls need to be designed and checked under working state method of design. A set of calculations have been performed for both RCC and masonry retaining walls with clear height of 4.0m to understand variation in primary loads, bearing capacity requirements, factor of safety achieved against overturning and sliding etc. To study all the parameters, it is essential to keep basic input data and code provision similar for all calculations. Hence, IRC code guidelines has been followed here. Primary loads considered are as follows:

- Dead load of structure
- Dead load of backfill soil
- Lateral earth pressure
- Live load surcharge
- Dynamic increment of earth pressure under seismic
- Horizontal seismic due to self-weight of structure

Retaining wall sections have been designed considering above loads, in such a way that sections are stable against sliding and overturning. Variation of following factors have been studied here for similar retention heights to achieve a conclusive decision. Following outputs have been compared:

- Bearing capacity required
- Factor of safety available under unfactored loads
- Magnitude of dynamic earth pressure

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• Magnitude of lateral seismic force due to self-weight
• Quantity of major items like concrete, reinforcement etc.

1. Objective

Main objective of this paper is to represent various design and cost related parameters for both RCC and stone masonry retaining walls and perform a comparison between the two. In future, this study may help any aspirant to select one between the two types in any construction project.

2. LITERATURE STUDY

Various literature studied are listed below:

- Sustainable Stone Masonry Blocks by P. Girish and Dr. K N Vishwanath
- Diagnostic of Stone Masonry Arch Bridges by Gyula Bögöly
- Comparative Seismic Assessment Methods for Masonry Building Aggregates: A Case Study By Nicola Chieffo, Antonio Formisano
- Lattice Discrete Modeling of Out-of-Plane Behavior of Irregular Masonry by Micaela Mercuri, Madura Pathirage, Amedeo Gregori, Gianluca Cusatis

3. ASSUMPTIONS AND CONSIDERATIONS

To perform the study, the location has been considered as a hilly region of high altitude with seismic zone V. Exposure condition has been taken as very severe, as in most of the cases, high hills are subjected to snow fall. For RCC retaining walls, for very severe exposure condition, grade of concrete, clear cover has been taken from respective IRC code [1]. For masonry structures, general code guidelines [3] followed to select the material properties. Properties of backfill soil considered of unit weight of 20.0 kN/m^3 and angle of internal friction as 30.0^o. Earth pressure has been evaluated as per Coulomb's theory. For earth pressure calculation and all other load calculations, guideline of IRC code [2] has been followed.

4. MATERIAL PROPERTIES AND INPUT DATA

All material properties and input data considered in the calculations are summarized below:
Unit weight of concrete 25.0 kN/m^3
Unit weight of stone masonry 26.0 kN/m^3
Unit weight of soil 20.0 kN/m3
Angle of internal friction for backfill soil 30.0^o
Coefficient of friction for sliding 0.5
Minimum depth of foundation 1.0m
Exposure condition very severe
Grade of concrete M40
Grade of reinforcement Fe500
Type of stone masonry coursed rubble masonry with 1:3 cement mortar

Seismic zone V
Zone factor, Z 0.36
Importance factor, I 1.2
Response reduction factor, R 1.0
Peak ground acceleration, Sa/g 1.0

5. ANALYSIS AND DESIGN METHODOLOGY

• For RCC retaining wall
After performing all load calculation, at first stability checks have been done. To do so, all loads coming at base and moments acting about toe have been calculated separately. Thus, ratio of total restoring moments due to vertical loads and total overturning moments due to lateral loads have been obtained about toe to satisfy the stability against overturning. Similarly, safety against sliding has also been checked by obtaining the ratio of total restoring friction force due to vertical load and total sliding force due to lateral loads. After that, maximum and minimum base pressure have been calculated. Optimum dimension of retaining walls have been interpolated in such a way so that, no negative pressure generates at base and least margin is kept in factor of safety against overturning and sliding.

Design of retaining walls have been done as per limit state method as per code [1] provision. All possible load combinations performed, and limit state of collapse and limit state of serviceability satisfied for respective combinations [2].
Seismic force has been considered for both stability analysis and limit state design.

• For masonry retaining wall
After performing all load calculation, at first stability checks have been done. To do so, all loads coming at base and moments acting about toe have been calculated separately. Thus, ratio of total restoring moments due to vertical loads and total overturning moments due to lateral loads have been obtained about toe to satisfy the stability against overturning. Similarly, safety against sliding has also been checked by obtaining the ratio of total restoring friction force due to vertical load and total sliding force due to lateral loads. After that, maximum and minimum base pressure have been

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calculated. Optimum dimension of retaining walls have been interpolated in such a way so that, no negative pressure generates at base and least margin is kept in factor of safety against overturning and sliding.

No specific guideline for limit state design of masonry retaining walls have been available in India. However, stress check at various levels have been done for normal case.
Seismic force has been considered for stability check, but stress check has been done for normal case only.

6. DESIGN FINDING

A. For stone masonry retaining wall of 4.0m retention height

Overall height = 5.660 m
Total base width = 3.600 m
Height / Base ratio = 0.629
Cross sectional area= 10.496 m^2

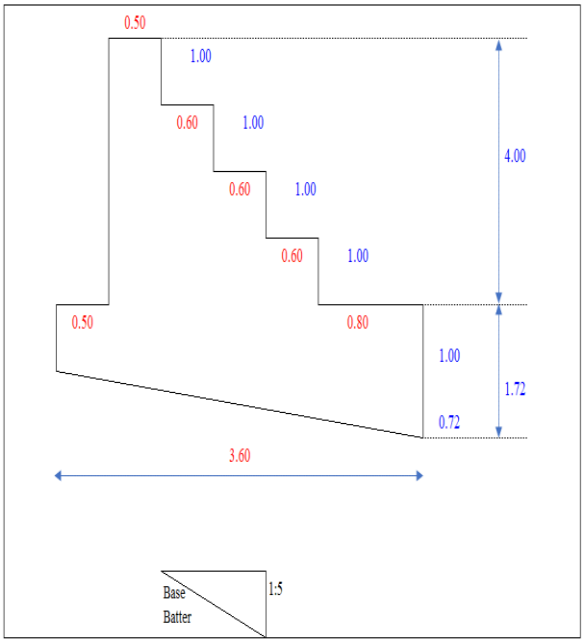

Fig 1: Sketch of Stone Masonry Retaining Wall

Output Summary

Maximum bearing capacity generated = 195.319 kN/m^2 under normal condition = 232.540 kN/m^2 under seismic condition
Minimum bearing capacity generated = 46.295 kN/m^2 under normal condition
= 2.244 kN/m^2 under seismic condition
Factor of safety against overturning
= 4.511 (> 2.0) under normal condition
= 3.598 (> 1.5) under seismic condition
Factor of safety against sliding = 2.446 (> 1.5) under normal condition
= 1.738 (> 1.25) under seismic condition
Total dynamic increment of active pressure at base = 51.978 kN
Total horizontal seismic force due to self-weight = 58.946 kN
Total quantity of stone masonry= 10.496 m^3/m
Approximate cost of major items, considering cost of raw material only is coming as Rs. 50,000/- per m.

B. For RCC cantilever retaining wall of 4.0m retention height

Overall height =5.500 m
Total base width = 3.950 m
Height / Base ratio = 0.718
Cross sectional area = 2.972 m^2

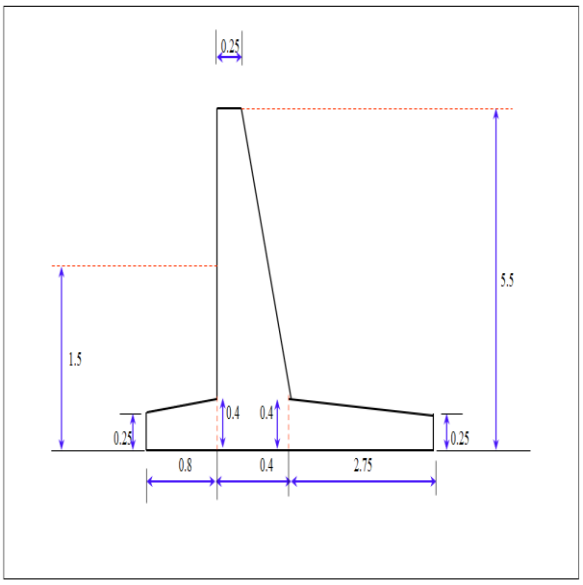

Fig 2: Sketch of RCC Retaining Wall

Output Summary

Maximum bearing capacity generated = 165.589 kN/m^2 under normal condition
= 193.490 kN/m^2 under seismic condition
Minimum bearing capacity generated = 63.895 kN/m^2 under normal condition
= 4.242 kN/m^2 under seismic condition
Factor of safety against overturning
= 3.912 (> 2.0) under normal condition
= 2.725 (> 1.5) under seismic condition
Factor of safety against sliding = 1.815 (> 1.5) under normal condition
= 1.311 (> 1.25) under seismic condition
Total dynamic increment of active pressure at base = 48.489 kN
Total horizontal seismic force due to self-weight = 16.450 kN
Total quantity of M40 concrete =

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2.972 m^3/m
Reinforcement quantity = 413 kg

Approximate cost of major items, considering cost of raw material only is coming as Rs. 65,000/- per m.

7. RESULT AND DISCUSSION

From the above data it could be seen that being a gravity type wall, the base pressure requirement of stone masonry retaining wall is much higher than that of RCC retaining wall. For stone masonry retaining wall, maximum gross base pressure generated is 18% and 20% more than RCC retaining wall in normal case and seismic case respectively.
Comparing factor of safety, it can be observed that, factor of safety against overturning in stone masonry wall is 15% and 30% higher than that of RCC retaining wall in normal case and seismic case respectively.
In case of sliding, factor of safety against sliding is 34% and 32% higher in case of stone masonry than RCC retaining wall in normal case and seismic case respectively.

Having self-weight of higher magnitude, total seismic force due to self-weight is about 3 times more in stone masonry retaining wall than RCC retaining wall.

Primarily it appears that total mass associated with the construction of stone masonry retaining wall is much higher than RCC retaining wall but in actual from sustainability aspect the case may not be same. Cumulative energy consumption to produce cement, reinforcement steel and energy associated with transportation of raw materials in high hill is much higher than that of stone masonry retaining wall as main raw material which is stone is mostly available from local quarry.

8. FURTHER SCOPE OF DEVELOPMENT

From the content and work of this report shows, undoubtedly stone masonry retaining walls are cheaper and sustainable than RCC construction. In the case of reinforcement concrete design, lots of advancement already done which includes limit state design, provision of ductile detailing etc. Regarding construction also, various works are going on concrete technology to make concrete durable by using admixtures. From sustainability aspect also, works are going on to use fly ash, plastic fibers, and various waste materials to make concrete sustainable and environment friendly.

On the contrary, field of stone masonry is not being addressed for quite a long time. Available codes are old. Latest revision and reaffirmations of stone masonry codes are not being done. Use of various admixtures to improve the tensile stress capacity of stone masonry could be explored to make such construction more acceptable. Whether excavated stones in hill roads could be adopted in stone masonry structures that could also be studied. Works are also required to assess durability and design life of stone masonry constructions. Behavior of such structures under seismic is of much interest as in most of the cases stone masonry are adopted in hilly regions which are in higher seismic zones.

9. CONCLUSION

The report presents that for similar retention height, stone masonry provides higher factor of safety against overturning and sliding with respect to RCC retaining wall but bearing capacity requirement for RCC retaining wall is much less than that of stone masonry. It is also to note, in general available bearing capacity in hilly region is much higher due to presence of rocky strata at shallow or moderate depth. Hence, stability wise stone masonry can perform satisfactorily.

Advancements and further works to improve its durability and strength by using admixtures, reused reinforcements etc. will be very helpful to make stone masonry work more acceptable. Revision with new code provisions if done, will also be appreciated.

Thus, it can be said, stone masonry walls could be a very economic and sustainable substitute of RCC retaining walls and further development could make it more appropriate.

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