

Study on Irregularly Shaped shotcrete shells in Tunneling

S. Vijayalakshmi¹, B. Harish Naik²PG Student, Department of Civil Engineering, Shri Shirdi Sai Institute of Science & Engineering, Vadiyampeta,
Andhra Pradesh, India.¹Associate Professor, Department of Civil Engineering, Shri Shirdi Sai Institute of Science & Engineering,
Vadiyampeta, Andhra Pradesh, India.²

ABSTRACT: In most large infrastructure projects where the tunnels yesterday's shotcrete part of rock reinforcement. Shotcrete is admixture of cement, aggregate, water and various additives such as accelerators that sprayed on such a rock surface. It is also possible to use steel fibers in this mixture, which go at a considerably greater tensile strength. In this case, usually rock reinforcement also consist of rock bolts, which bolts are different in length among others can be embedded in the rock. These can then be with washers on the outside of the concrete surface to prevent excessive tension will occur at the bolts. Normally, empirical methods or assumption that the spray concrete acts as a concrete slab to determine how rock reinforcement should be designed. This provides a rock reinforcement that can probably be oversized, which means that there is a need of design methods that provide an accurate picture of how the shotcrete work. Previously numerical models used to investigate a sprayed concrete reinforcement. This work is a preliminary study to a larger research project on shotcrete. The report reviewing the existing literature on the fields, trying to describe the practical problems occurs during construction, and using a development of the numerical model previously used to analyze the same problem in 3D. The results show that the conclusions made earlier are relatively well in 3D and that several of the conclusions of the earlier study also consistent with this model. This study concludes with suggestions for further research and emphasizes the need to use the rock mass as part of rock reinforcement in future models, where especially the adhesion that occurs between shotcrete and rock is an important parameter because the number of crimes in the shotcrete seems interact with this parameter.

KEYWORDS: Shotcrete, Accelerators, Steel Fibers, Tensile Strength, Reinforcement.

I. INTRODUCTION

Time the road system will be enhanced knowledge is needed in underground construction, since several of the present and future road and railway infrastructure project probably will be located underground in major cities. An important part of underground construction is the rock support. This is usually carried out using a combination of rock bolts and shotcrete, which is concrete this is sprayed onto surfaces instead of casted in forms. Shotcrete has usually been designed as a regular concrete slab which is different from how it works in-situ. Infrastructure projects have become more and more important in the modern society. The roads and railroads that connect the urban areas form the network of the modern economy. As in other parts of the developed world, the big and far-reaching infrastructure projects have been increasingly difficult to initiate and complete, depending on several factors that impact the development of urban infrastructure. The factors have meant that the infrastructure development has been very slow and complicated in developing countries during the later part of the 20th century. The factors, i.e. environmental laws and public disapproval of infrastructure projects, have made surface construction so difficult that most large-scale infrastructure projects probably will consist of tunnels in the future, all round. This implies that underground construction technology will be very important in the future in the countries with similar kind of problems like infrastructure development. The methods currently used will probably be improved to ensure a safer and faster way to create tunnels. The change from surface infrastructure to underground infrastructure will also be expensive, and it is important to develop cost-efficient

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methods to create underground openings. Because of these reasons, investigations of the properties of the parts involved in underground construction are very important, from the initial investigations to the construction of the shotcrete lining. The cost of the construction can be reduced when the knowledge is expanded, and society can gain significantly by these improvements.

II. PREVIOUS WORK

The model developed by Nilsson (2003), is the basis of the numerical modelling presented in this report, which is based on the same geometrical and material properties. The numerical simulations of interest in this report consist of a parameter study of an irregular shotcrete slab. The parameters investigated were the irregularity of the slab, the thickness of the slab, the position of the rock bolts and the boundary conditions used in the simulations. The stiffness of the slab was indirectly changed as the thickness and shape was changed.

Two different irregular slabs were used. The first was quadratic and $4 \times 4 \text{ m}^2$, with a rock bolt placed in the middle of the slab. The other was $6 \times 6 \text{ m}^2$, with rock bolts placed either at the peaks of the slab or at the depressions of the slab. Similar simulations were also performed on a flat slab to compare the effects of the irregularity. Two different thicknesses on the shotcrete slab were used, 40 mm and 80 mm, both for the irregular slabs and the flat slabs. The load from the rock mass was simulated by a uniformly distributed load on the surface of the slab. Two different boundary conditions were used, simply supported ends and fixed ends.

III. DESIGN AND CONSTRUCTION

A. DESIGN

The design is usually based on empirical methods, which means that the experience from earlier projects is used to give an estimation of what will be a reasonable rock support. For any typical Q-value or RMR values (rock mass rating) or any other empirical parameter (explained below) will give a “typical rock support”, based on experience. The design work will give the construction firm three design values can be changed depending on the conditions of the rock surface after the drilling and blasting. The Q-value or RMR-values depend on the measuring method. They construction firm will be given quite detailed instruction for each part of the tunnel. The specified design factors that are:

- Shotcrete lining thickness
- Shotcrete lining strength
- Rock bolt distance

B. CONSTRUCTION

The shotcrete lining is just one part of the construction phase which consists of a large organization with many people with different knowledge of the different parameters that affect the ground. They workplace tends be limited in volume and communication is very difficult, according to Nord and Stille. Because of all these factors it is very important to have simple blueprint and construction directions. The time is also very important since the opening date for the tunnel is usually decided, and the whole project will be influenced by this. Time is often more important than cost when the economic benefits will be quite small.

The construction firm will start spraying the shotcrete lining after the drill and blast has been done. The drill and blast procedure includes:

- Pre-grouting
- Drilling
- Charging
- Blasting
- Scaling
- Mucking

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IV. ASSUMPTIONS AND SIMPLIFICATIONS USED IN THE ANALYSIS

Since the interaction between shotcrete, rock and the rock bolts is so complicated, a number of simplifications and assumption have been used in this report. These assumptions and simplifications will obviously influence the results of the simulations. This makes it very important to describe the assumptions in detail. The bond strength between the shotcrete and rock surface has not been included in the numerical model. The interface strength will be described by the Mohr-Coulomb failure the 3D-model.

The rock bolts will not yield and are modelled as fixed elements on the surface. This is a somewhat realistic assumption since the concrete probably will fail before the bolts.

The maximum and minimum principal stresses have been used to estimate the effects of the shotcrete shell. These should be able to represent the stress states of the shotcrete lining, but there could be stress situations that does not reflects the overall stress distribution of the shell and where this methods could give faulty results.

The shotcrete thickness will show a regular variation. In reality, the variation will be far more chaotic, which can be difficult to simulate. There are no sharp edges at the rock surface, the local geometry is “regular” The global geometry will be smooth and dominated by a variation dominated by sinus- waves, while the rock surface is dominated by chaotic variations. The loads on the shotcrete shell will be modeled by uniform pressure. In reality, the rocks that rest on the shotcrete shell will obviously have a stiffness, which allows the load to be redistributed on the shell, which can increase the load-bearing capacity of the shotcrete compared to the uniform pressure.

V. MODEL ANALYZED

A load that simulates the force from a single rock is applied on top of the shotcrete lining. The load consists of uniform pressure. The position of the load is shown in Figure.

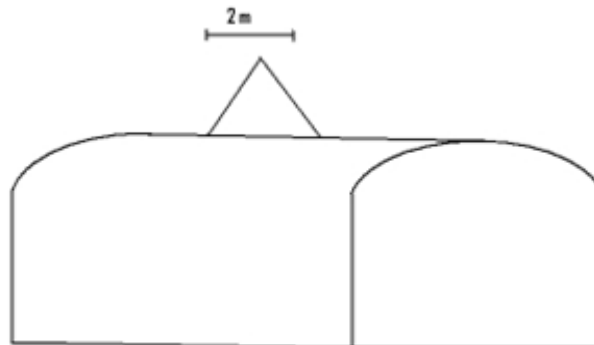


Figure shows the load from a single rock on the shotcrete lining. In this case, the cracks in the rock mass cannot restrain the rock, which instead will be carried by the shotcrete lining.

The load will consist only of pressure, and hence will not have any stiffness. This is somewhat unrealistic, since a real rock has stiffness and could redistribute the load when the rock support is changed, for example if there is a failure in some part of the rock support that is subjected to the load from the rock. The loads are sometimes carried by the shotcrete lining, and in other cases where the rock formations are very big, one or more rock bolts will be applied at the surface of the single rock to fasten it against the rest of the rock mass. Three different variations of the model will be used: the regular model, the irregular one with the rock bolts at the peaks and the irregular one with the rock bolts at the depressions. The thickness of the shotcrete lining is changed from 25 mm to 125 mm for the three different models but is uniform for all three models, in order to study the influence of the shotcrete thickness.

The rock bolt that will be subjected to the highest stresses will represent the lining when the maximum principal compressive and tensile stresses and the influence length are calculated. The initial simulations showed that the maximum tensile and compressive principal stresses always appeared at the edges of the washers attached to the rock bolts. In the first example where the load effect was simulated by a uniform pressure on the tunnel ceiling, the rock bolt washers closest to the area subjected to the load were obviously most affected. The maximum principal

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stress has been defined as the highest stress that converges along the edge of the rock bolts washers. Since the washers are simulated by quadratic elements there is a theoretical divergence at the edge of the rock bolt. Instead the highest value that converges by the edge of the rock bolt washer has been used.

The deflection of the tunnel ceiling in the middle of the area that is subjected to the load will also be collected from the model. The influence of the high tensile principal stresses along the edges of the rock bolts have been estimated by using the “influence length” of the stress distribution. This has been estimated as the multiple of the rock bolt length that has been subjected to more than 80 % of the maximum tensile stress. An example is shown in Figure, where the influence length is 1.2.

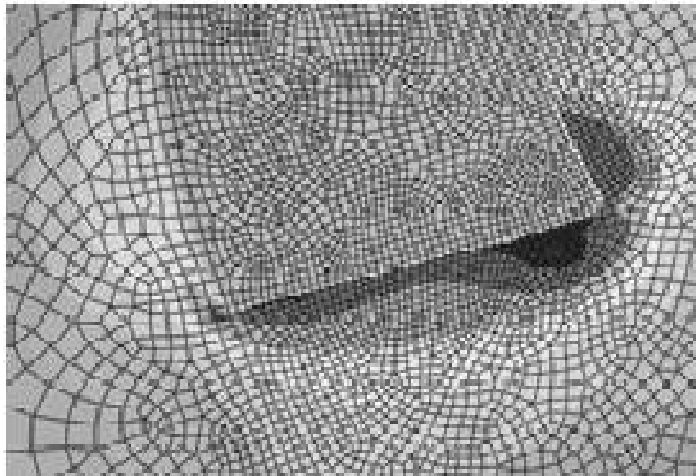


Fig 1: Influence length of the maximum tensile principal stress along the edge of the bolt washer where the influence length is 1.2

The following results will be collected from the numerical simulations:

- Maximum principal tensile stress at the rock bolt subjected to the largest load.
- Maximum principal compressive stress at rock bolt subjected to the largest load.
- Influence length at rock bolt subjected to the largest load.
- Deflection of the tunnel ceiling relative to the vertical axes.

The aims are to:

- Identify the differences between the stress distributions of the models.
- Estimate the possible damage of the models depending on the shotcrete thickness.
- Estimate the stiffness of the different models depending on the shotcrete thickness.
- Assess the difference between the rock bolt placement patterns

V. RESULTS

The results for the above model shows that the shape of the shotcrete lining influences the stresses in the lining significantly. The numerical analysis showed that both the maximum tensile stresses and the maximum compressive stresses were located at the bolt washers.

The results confirm that, where the irregular shotcrete linings had a higher load bearing capacity compared to the regular lining. It also confirm the result that the rock bolt pattern where the bolts were placed at the peaks of the surface irregularities had a higher load bearing capacity compared to the pattern where the rock bolts were placed at the depressions of the surface irregularities. The difference between the irregular and the regular shotcrete linings seems to increase when the thickness increases, which means that the results are somewhat different.

The stresses were located along the edges of the bolt washers, but the exact location along the bolt washer depended greatly on the shotcrete thickness. The distribution of the maximum principals stresses along the edge of the bolt

washers, where the stress converges to the edge closest to the load as the shotcrete thickness increases. The dark areas symbolize approximately 80 % of the maximum stresses. In-situ, the bolt washer could probably move and rotate somewhat compared to the model where no movement or rotation was allowed along the surface of the bolt washer. This could reduce the maximum principal stresses at the washer.

The minimum principal stresses along the edge of the bolt washer will behave quite differently. This pattern has noticeable higher compressive stresses at the rock bolts, especially when the shotcrete lining is thin, but the difference decreases as the shotcrete lining thickness increase. As the thickness of the lining increases, it seems that the regular shotcrete lining will have higher compressive stresses compared to the irregular lining with any of the bolting pattern. This might suggest that the stress is re-distributed differently in the regular lining when the thickness increases than for the irregular lining with either bolting pattern.

As previously stated, the influence of the stresses on the load bearing capacity of the lining was also investigated by using a measurement of the stresses that can be called the influence length. This is the ratio between the lengths of the stress that surpass 80 % of the maximum principal stresses along the bolt washer, compared to the length of the bolt washer. This should be a somewhat accurate measurement of the damage inflicted by the load.

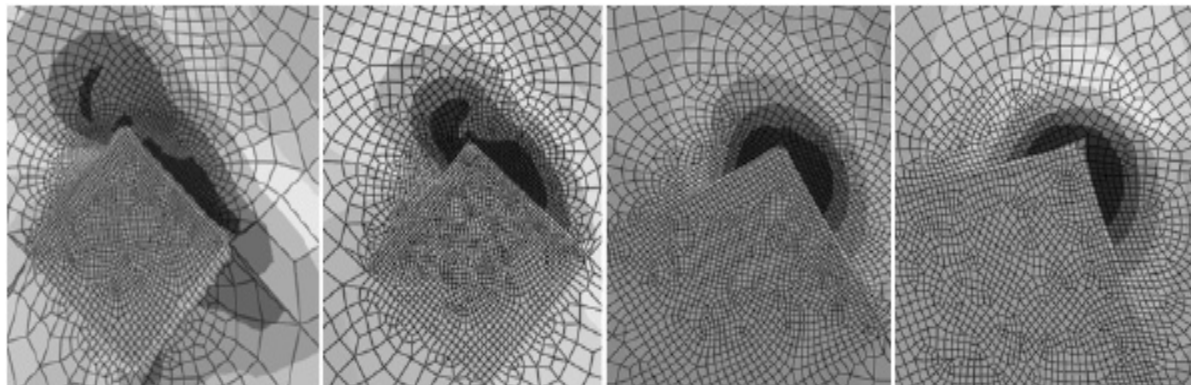


Fig. 2: Minimum principal stress along the bolt washer

Fig 2. The rock bolt pattern with a high influence on the load bearing capacity.

It confirms the results from which shows that when the rock bolts are placed at the depressions of the surface, it can decrease the load bearing capacity compared to the regular lining. This irregular model with the bolting pattern at the peaks of the irregularities is favourable compared to both the regular lining and the rock bolt pattern where the rock bolts are placed at the depressions of the irregularities.

The difference in stress distribution around different bolts if the rock bolts are placed arbitrarily along the shotcrete lining. It is obvious that the rock bolts that are placed on the depressions of the shotcrete lining give rise to higher maximum principal stresses than the rock bolts placed at the peaks of the shotcrete lining. This also confirms the conclusions put forward that the shotcrete around rock bolts placed at the peaks are dominated by compressive stress instead of tensile stress. For the rock bolts placed at the depressions of the shotcrete lining, the situation is reversed, and they are surrounded by high tensile stresses.

Fig.3. shows the deflection in the lining ceiling for different shotcrete thicknesses. It is obvious that the regular shotcrete lining has a much higher flexibility compared to the irregular lining with any rock bolt pattern. The results also show that the rock bolt pattern with the rock bolts placed at the depressions results in a lining that has a higher stiffness than the rock bolt pattern with the rock bolts placed at the peaks of the irregularities. This effect also increases when the thickness of the shotcrete lining decreases.

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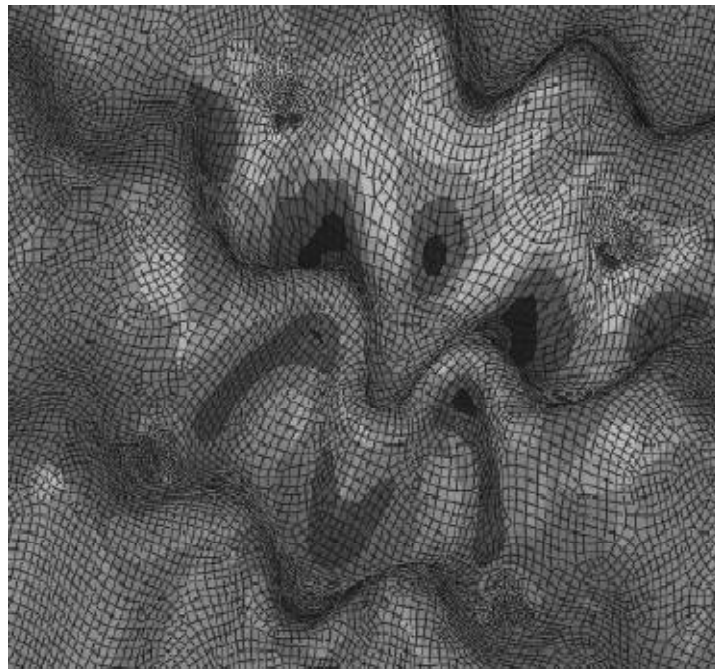


Fig 3. Stress distribution for a shotcrete lining with rock bolts placed arbitrarily along the lining.

VI. CONCLUSION

The shape of a tunnel wall after the task of blasting and drilling is typically irregular. After the tunnel wall is sprayed with shotcrete, the resulting shotcrete surface will also be irregular and have a big variation in thickness due to uneven shotcrete coverage. Today, most design models assume that the shotcrete surface behaves as a concrete slab. The existing literature on the subject is reviewed to gain an understanding of the important parameters that affect the shotcrete shell. In addition to the theoretical research the relevant parameters that influence the behavior of a tunnel lining are discussed and the quantitative and qualitative importance of each parameter is estimated. Some of the practical problems that arise when a shotcrete lining is constructed are discussed. These problems complicate the design in many ways, and makes shotcrete design very different from ordinary structural design. The behavior of a shotcrete rock support system subjected to several load combinations using different models that simulate irregularity and variation in thickness is analyzed. The results show that the influence of the irregularity is highly dependent on the shotcrete thickness and shape and that the placement of the rock bolts is very important. Several other aspects are discussed as well.

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