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Research article

Numerical modelling of the Effect of Fire on Fiber-Reinforced Concrete in Tunnel Lining Using the Finite Element Method

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English Extended Abstract

Summary

During a fire, in a short period of time, the temperature in the tunnel reaches about 1300˚c, which itself leads to many chemical interactions in the structural and non-structural components of the tunnels and changes their performance depending on the depth and the quality of these interactions, the structure can be seriously damaged and in the worst case, the stability of the tunnel can be compromised. In this research, an attempt was made to investigate the behavior of the tunnel concrete lining under fire conditions with the help of finite element numerical analysis. The ordinary concrete lining of the tunnel was affected by the fire, and the temperature of the tunnel reached about 1300˚c, and the behavior of its concrete lining was investigated. Then, according to the recommendations of the regulations to use fiber concrete to reduce the effects of fire, fiber concrete of steel fiber concrete, glass fiber concrete, and polypropylene fiber concrete were modeled under fire conditions. Considering the effect of fire on the tensile strength of concrete as well as its deformation, the focus of the current research was on the effect of fire on the tensile damage and deformation of concrete. The behavior of concrete lining is the same as behavior in normal conditions. The results of this research showed that steel fiber concrete showed the best performance against fire. The deformation of steel fiber concrete was reduced by 75% compared to concrete without fibers. The deformation of polypropylene fiber concrete was reduced by 15% compared to concrete without fibers. Deformation of glass fiber concrete showed a 10% decrease compared to concrete without fibers.

Introduction

In general, two phases of materials are evident in concrete: the solid phase of which includes a combination of cement and other stone materials and additives, and the liquid phase of which includes water that is present in concrete pores. By applying fire to concrete parts, in addition to the reactions that occur in the solid phase of concrete, changes also occur in the liquid phase of concrete, and gradually, a gas phase is formed in concrete, which includes water vapor in the holes. In the construction of concrete parts of tunnels, concrete with high compressive strength is mainly used, which increases the compressive strength of concrete and reduces the permeability and porosity of concrete. By reducing the permeability of concrete, the passage space for water fluid and water vapor in concrete is reduced, and the concrete is more affected by fire. Usually, the water in the voids of the concrete starts to turn into water vapor at a temperature of 100 degrees Celsius, and gradually, after passing the temperature of 150 degrees Celsius, all the water in the voids of that part of the concrete turns into water vapor and starts It concretize into the flow in the colder inner parts and accumulates there. As the fire continues and the temperature increases in the concrete, the rate of formation and conversion of water-to-water vapor and further, the migration of water vapor to the inner

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layers increases; To the extent that the water vapor particles occupy part of the concrete penetration valves and by saturating the holes in that part of the concrete, they create barriers that prevent the passage of more water vapor. With the formation of layers saturated with water vapor or a mixture of water vapor and water, and gradually with the influx of water vapor from the hotter parts of the concrete, the pore pressure in this area of the concrete begins to form and develop, and as a result, the tensile stress lines are formed in that part of the concrete. To the extent that with the increase of heat and water vapor penetration in concrete, pore pressure and tensile stresses in the area of water and water vapor accumulation exceed the tensile strength of concrete and lead to the separation of that part of the concrete from the concrete piece. Figure 1 shows the phenomenon of spalling or separation of concrete.

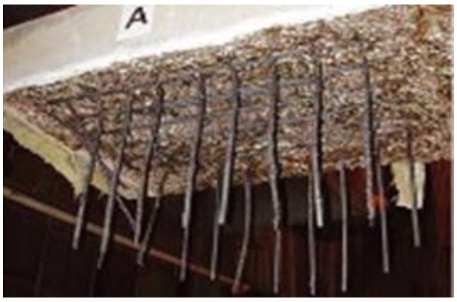
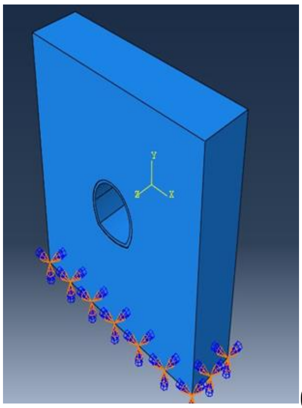


Fig 1. Spalling in concrete

Methodology and Approaches

In this research, with the help of Abaqus software, a tunnel with an opening width of 5 meters and a length of 10 meters with a concrete cover thickness of 50 cm was dug in a limestone ground with dimensions of 70 meters by 70 meters. Input variables to the model include stress components, Poisson's ratio, Young's modulus, heat transfer coefficient, thermal expansion coefficient, specific heat capacity, and plasticity properties of concrete. To model the ground around the tunnel structure, its material is considered to be limestone. Also, according to Figure (2-(a)), the movement of the sides of the concrete lining and the ground in three directions, as well as in the direction of the anchor caused by them, has been prevented. The contact between the concrete lining of the tunnel and the bedrock is selected as a Tie type to prevent additional movements of the concrete lining. Meshes are defined as a Sweep. Also, in order to achieve the desired goal, the size of concrete cover meshes in static analysis is 1 meter, and the size of rock meshes is 5 meters. Also, in the heat transfer analysis, 0.05 meter meshes were used in the concrete lining and 5 meter meshes were used in the stone (Figure 2- (b)).


(a)

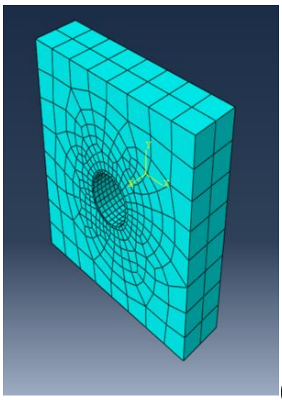

(b)

Fig 2. Figure 2 (a) and (b): A view of the constructed model

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Results and Conclusions

In this research, the tunnel's concrete lining was modeled in 3D with the help of Abaqus software in the face of fire. The concrete lining of the tunnel was investigated in two cases. The first case of tunnel lining made of concrete without fibers and tunnel lining made of steel fiber concrete, polypropylene fiber concrete, and glass fiber concrete was modeled without applying a fire load. Then, in the second case, fire was also added to the conditions of the model. The modeling results show:

1- Fire has a negative effect on the concrete and causes it to be reduced.

2- The presence of steel fibers has a significant effect on concrete and reduces damage caused by fire.

3- The presence of steel fibers has a good effect in reducing the deformation of the tunnel's concrete lining.

When faced with fire, the steel fiber concrete lining is less affected than other samples. The deformation of steel fiber concrete was reduced by 75% compared to concrete without fibers. The damage and deformation of the polypropylene fiber concrete lining is more than the glass fiber concrete lining, and it does not show proper performance.

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