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Research Article

# Stress Analysis of Concrete Domes under the Rockfall Impact

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ABSTRACT

In this study, the effects of impacts caused by freely falling rocks from different heights on the structural performance of concrete domes were investigated. The variations of the maximum stresses induced by rocks falling from different elevations depending on the diameter of the falling rock and the cross-sectional wall thickness of the concrete domes are presented. Domes are important structural elements frequently preferred by designers due to their aesthetic appearance and engineering properties. As they are frequently preferred, they are exposed to different natural disasters. Rockfalls are an important natural disaster that causes damage to structures built on rugged terrains with unstable soils. Knowing the extent of the damages caused by this disaster will shed light on the design of the structures built or to be built. The results of the structural analyses show that the kinetic energy caused by the increase in the elevation of the rock fall increased the structural damages (maximum stress) considerably, and these increased structural damages were tried to be controlled with the section wall thickness. As a result of the analyses, the stress values of the dome were determined according to the height at which the rock falls. It is thought that the results of these analyses will give a preliminary idea to structural engineers and architects at the design stage.

## Introduction

Concrete domes have been one of the structural elements frequently used by architects and engineers from past to present with their aesthetic appearance and weight/span ratio. It has been preferred because of its structure that can uniformly spread the service loads it is exposed to on its inclined surface, its ability to offer the designer an almost unlimited range of design shapes, and the ability to design large span areas without using vertical carriers [1]. When strengthened with reinforcement, both tensile and compressive forces that it can make dome structures capable of serving many engineering structures [2]. In addition, with today's technological developments and the improvement of the strength and material properties of the concrete material used in the design, it has increased the options available for the structural design of concrete dome elements and expanded the limits of architectural design and designer [3].

In mountainous and hilly geographies, the sudden movement of the rocks, which are detached from the main mass on the slope surfaces due to physical effects, in the direction where they break their physical bond with the bedrock under the influence of gravity, is called rockfall [4]. This effect, which can be caused by various factors such as triggering of earthquakes, freeze-thaw cycles after snowfall, heavy rains and landslides, can occur in a wide range from mm-sized gravels to enormous rock blocks [5,6]. The strike energy resulting from the direction, mass and velocity of the falling rock masses depends on many structural and non-structural factors such as the angle of fall, the amount of vegetation in the area where the event occurs, the geometry and weight of the rock. Especially hillsides with large slope angles, steppe-style geographies without dense vegetation and areas with fractured rock structures are likely to be highly vulnerable to rockfall impacts [7]. Comprehending the mechanical and therefore theoretical background of the rockfall event, including the cause of occurrence and the areas of potential impact, is of great importance in terms of assessing and minimizing the risk [8].

Rock falls, which pose a danger to human life and urban infrastructure in many areas around the world, can cause great damage to many engineering structures in the form of superstructures and infrastructures, which are essential for the maintenance of daily life due to their easy occurrence and high kinetic energy due to their mass and velocity [9]. Some protective measures can be taken to protect structures from rockfall impact. Measures such as barriers, reinforced earth embankments, cage or cable steel nets are some of the methods used to minimize the rockfall impact [10]. In addition, restriction of construction in such landslide areas can significantly mitigate the risk of damage [11].

In this study, concrete domes with a span of 9 m were analyzed under dynamic effects caused by the fall of rock masses with 3 different diameters from 5 different heights utilizing Ansys-Explicit Dynamic solver [12]. Although different types of structures have been solved for rockfall effects in the literature, studies on concrete domes are quite limited. In this respect, the originality of the study is provided by parameters such as rockfall scenario, dome span and thickness. The obtained analysis results provide structural safety assessments of concrete domes under rockfall impact depending on different heights, as well as preliminary design ideas for structures to be built in regions where such damage hazard exists.

## Material and Method

In this study, stress and displacement values were determined by considering five different rock fall heights (15 m; 30 m; 45 m; 60 m; 75 m) [13] and section thickness of the concrete dome as 0.5 and 1 m. The material properties of rock and concrete are given in Table 1. Mohr-Coulomb material model was used for concrete.

Table 1. Mechanical and physical properties of the materials used in the analyses.

| Material Types | Density ($kg/m^3$) | Elasticity Modulus (MPa) | Poisson Ratio |
|---|---|---|---|
| Concrete (C35) | 2314 | 30000 | 0.200 |
| Rock (Sandstones) | 2350 | 34000 | 0.234 |

Some parameters were used for the Mohr-coulomb concrete model. These parameters are Initial Inner Friction Angle = 30°; Initial Cohesion= 3 MPa; Dilatancy Angle = 10°; Residual Inner Friction Angle = 25°; Residual Cohesion= 1.5 MPa, respectively.

The inner diameter of the dome is designed as 9 m. It is assumed that the dome is manufactured as concrete. Figure 1 shows the image of the analyzed dome. Falling rock masses can vary in a wide range of 0.5 $m^3$-25 $m^3$. Therefore, it is assumed that the rock is spherical and the sphere has 3 different diameters (1 m, 1.5 m and 2 m) [12]. It is assumed that the rock mass hits the concrete dome at the centre of gravity. The free fall velocity was determined according to the fall height of the rock. The fall velocity and analysis end times are given in Table 2.

Table 2. Mechanical and physical properties of the materials used in the analyses.

| Drop Height (m) | Drop Velocity (m/s) | Analysis Time (s) |
|---|---|---|
| 15 | 17.15 | 0.1 |
| 30 | 24.26 | 0.1 |
| 45 | 29.71 | 0.1 |
| 60 | 34.30 | 0.1 |
| 75 | 38.35 | 0.1 |

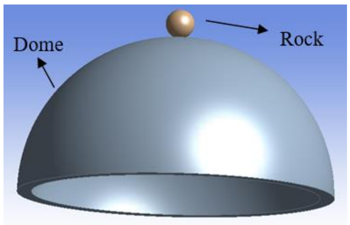
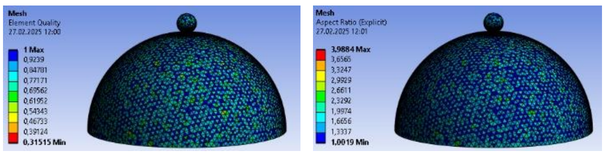



Figure 1. Dome and falling rock

Frictionless contact is defined between the dome and the rock. 'Frictionless Contact' is defined between the dome and the rock. Mesh thickness was selected as 0.25 m for the dome and 0.25 m for the rock. In addition, the mesh thickness in the contact zone was selected as 50 mm to increase the sensitivity of the analysis results. In the mesh convergence analysis, when these mesh settings are increased, the values change by 3%. The average element quality is 0.83 and the average aspect ratio is 1.60. For boundary conditions, the base wall thickness surface was selected and a fixed support was assigned. The weights of the materials are taken into account for the analysis. In addition, 1.5 $kN/m^2$ for live load, 1.25 $kN/m^2$ for snow load, 0.08 $kN/m^2$ for wind load, 0.2 $kN/m^2$ for cladding load and 3.03 $kN/m^2$ for dead weight.



(a) (b)

Figure 2. Mesh quality (a) and aspect ratio (b)

A total of 60 models were analyzed. H1, H2, H3, H4 and H5 are the free fall velocities depending on the fall height; Q1, Q2 and Q3 are the diameter of the rock mass; T1, T2 are the wall thickness of the concrete dome. All parameters used in the structural analyses are given in Table 3.

Table 3. Mechanical and physical properties of the materials used in the analyses.

| Parameters | Value (m) |
|---|---|
| H1 | 15 |
| H2 | 30 |
| H3 | 45 |
| H4 | 60 |
| H5 | 75 |
| Q1 | 1.0 |
| Q2 | 1.5 |
| Q3 | 2.0 |
| T1 | 0.5 |
| T2 | 1.0 |

## Results and Discussion

In this study, the stresses induced by the fall of a rock with three different diameters from five different heights to the centre of gravity of a concrete dome with an internal span of 9 m were investigated. Figure 3 shows the stress values on the concrete dome as a result of the rock with diameter Q1 falling from five different heights for wall thickness T1.

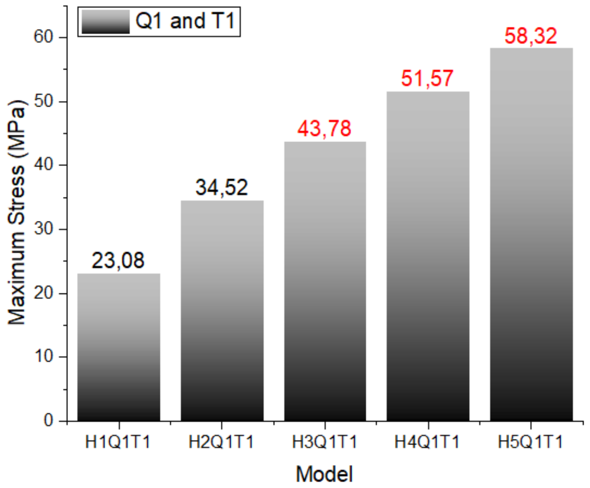



Figure 3. Stress values depending on Q1 and T1 parameters

While the minimum stress value was obtained in the H1Q1T1 model, the maximum stress value was obtained as 62, 8 MPa in the H5Q1T1 model. According to these results, if the concrete dome has a wall thickness of 0.5 m, rockfalls with a diameter of 1 m falling from a level higher than 15 m pose a danger to the concrete dome. Figure 4 shows the maximum stresses that occur when rocks of diameter Q2 fall on concrete domes with wall thickness T1. Since the stress values for a rock mass of diameter Q2 are quite high at all height levels, it is understood that the T1 diameter is insufficient for a rock mass of this diameter.

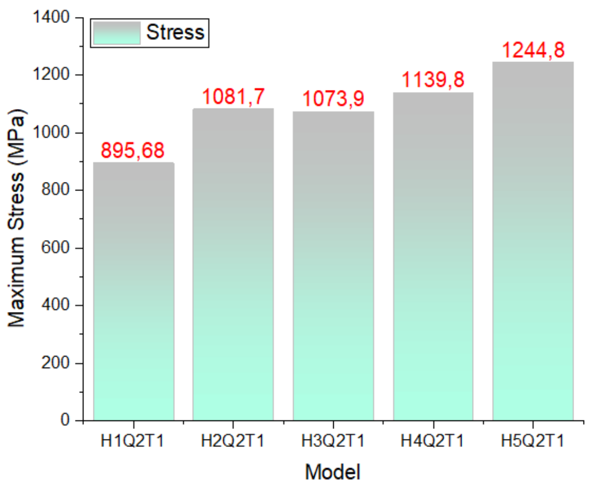



Figure 4. Stress values depending on Q2 and T1 parameters

Figure 5 shows the maximum stresses induced by a rock of diameter Q3 falling on concrete domes of wall thickness T1. Diameter Q3 is the largest diameter in this rockfall scenario, which is 8 times larger in volume than a spherical rock of diameter Q1. In addition, a rock mass of diameter Q3 falling from 15 m generates a stress of 6665.3 MPa on concrete material with C35 class. It is seen that the wall thickness of T1 is quite inadequate for a rock mass of Q3 diameter.

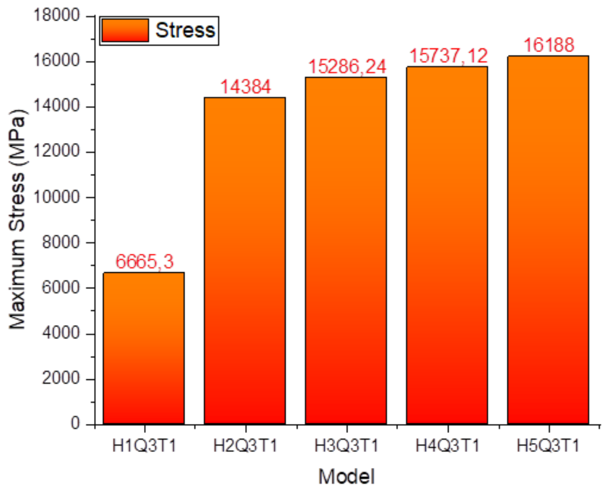



Figure 5. Stress values depending on Q3 and T1 parameters

In Figure 6, the maximum stresses of the dome with wall thickness T2 as a result of the dynamic effect of the rock with diameter Q1 are visualized. The results show that the stresses are within the range of stress values that C35 concrete can withstand. For this reason, it is understood that the T2 cross-section is sufficient in cases where rocks with Q1 diameter fall up to 75 m height.

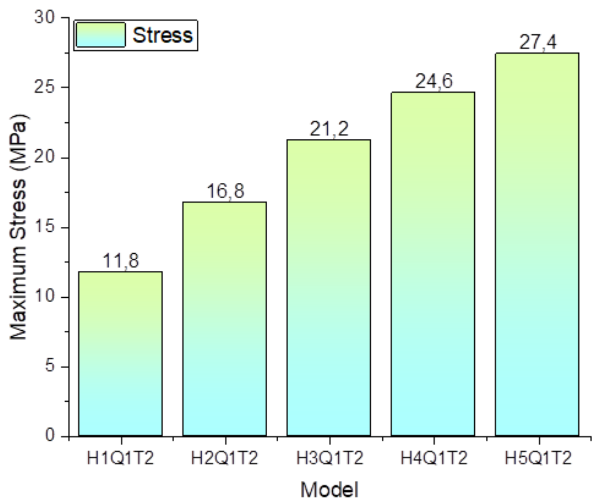



Figure 6. Stress amount for parameters Q1 and T2

The stress values of the concrete dome with a wall thickness of T2 at the apex of the dome due to the fall of Q2 diameter rocks are shown in Figure 7. The results show that the T2 cross section is sufficient for Q2 diameter rocks falling from 15 m, but the concrete strength is exceeded for Q2 diameter rocks falling from higher than 15 m.

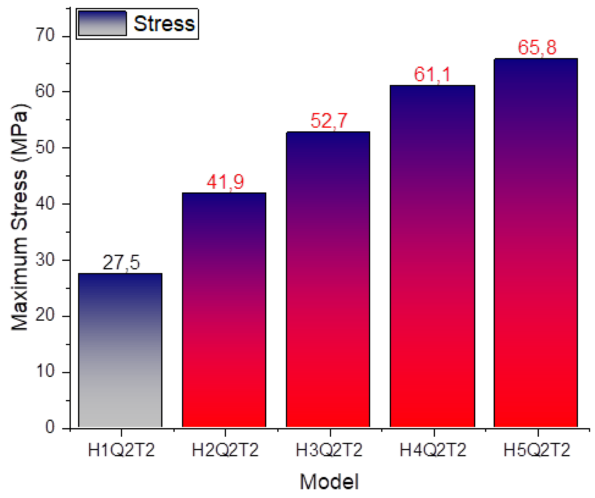



Figure 7. Stress amount for parameters Q2 and T2

For wall thickness T2, the maximum stress values that occur in the concrete dome due to the fall of Q3 diameter rock are shown in Figure 8. The stress values show that the T2 cross-section is at the limit for Q3 diameter rocks falling from 15 m, and the load that the T2 cross-section can carry is exceeded for fall elevations higher than 15 m.

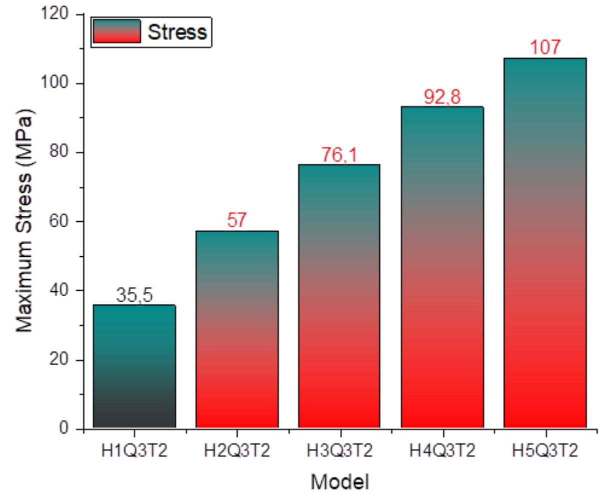



Figure 8. Stress values depending on Q3 and T2 parameters

## Conclusion and Suggestions

In this study, the stress values resulting from the fall of rock masses with three different diameters from five different heights on concrete domes with two different wall thicknesses were analyzed. As a result of the analyses, the following results were obtained.

1-Concrete domes with T1 wall thickness are unsafe for all rock diameters in rock falls above 15 m height.

2-Domes with T2 wall thickness can safely transfer the dynamic impact up to a height of 75 m for rocks with a diameter of Q1.

3-Domes with T2 wall thickness can absorb the energy created by Q2 and Q3 diameter rocks only for 15 m height. For other heights, the dome cannot carry this dynamic load.

In the past and today, dome-style structural elements are frequently used in both religious, social and cultural buildings. Although these structures depend on the geographical structure in the location where they will be built, they can be built on a slope. With this study, the structural performance of the dome to be constructed against rock falls against the specified parameters was determined. The analysis results obtained in this study are intended to give engineers and architects a preliminary idea before design.

## Ethics committee approval and conflict of interest statement

There is no need to obtain permission from the ethics committee for the article prepared

There is no conflict of interest with any person / institution in the article prepared

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