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# Study on the Features of Critical Arch in Granular Materials by the Developed Trapdoor Apparatus

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## 1- Introduction

In case of forming a stable arch in a granular medium due to successive particles removal, the interaction of the particles together leads to maintaining them against the failure caused by applied stresses from adjacent materials.

In an experimental test called "trapdoor test", the generation of arch can be studied. An arch can be formed over a trapdoor through granular materials as it is shown in Fig. 1.

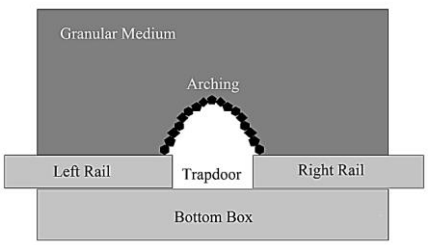


**Fig. 1. Formation of stable arch over a trapdoor**

Arching is a result of shear stress mobilization among granular materials. The shear stress is mobilized by relative displacement with respect to each other and this arch-formation is generated among the particles. The particles below the arch are not balanced and they fall over, while the particles above the arch remain in a static balanced condition. Although the arching formation can be considered as a transfer of pressure from a yielding mass of soil onto adjoining stationery parts, as done in the literature, this paper discusses the arching as a formation of a stable arch in granular materials using trapdoor tests. In this study, the formation of the last possible arch generated over a wide opening is investigated. Cohesionless granular materials are used in this study.

## 2- Experimental program

The developed trapdoor apparatus is an appropriate device to investigate how an arch is generated through cohesionless materials. Fig. 2 presents this setup and the corresponding parts.

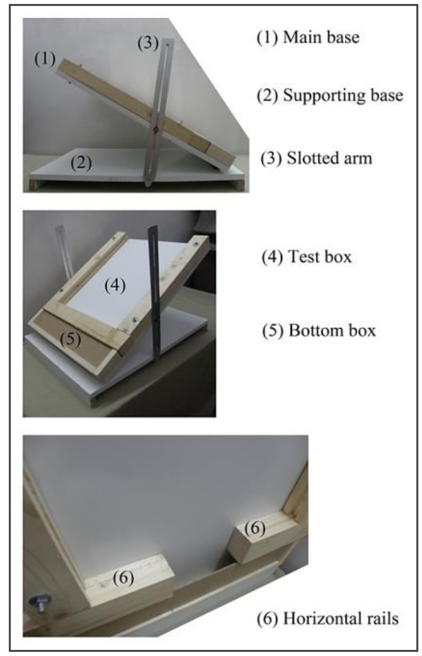


**Fig. 2. Parts of the developed trapdoor apparatus**

The device includes a variable trapdoor width, n test box with adjustable inclination, and a movable base. This setup can be considered as a modification of a so called trapdoor test already introduced in the literature. In this paper, the main base is clamped at directions by inclinations angle $\theta =$ zero, 10, 20..., and 90 degrees with respect to the horizontal, in order to study the process of arch formation along with its dimensions over various widths of trapdoor. It is noted that the trapdoor width is increased 2 mm at each step of the test procedure.

This paper concentrates on two significant events related to arching, which were observed in tests performed by the developed trapdoor apparatus. The first event is the parameters corresponding to the situation when the stable arch will be at the verge of failure, and second, the situation of the granular medium after which the no arch can be generated.

Some pebbles and plastic spheres called "rockfills" and "beads", respectively were used as granular materials. The beads have been set in two layouts: loose and dense. For the loose array, the particles are in a column-like layout. For the dense array, the beads are

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placed over each other in such a way that they are placed between the two underlying ones. Table 1 gives three properties of these non-cohesive materials, including internal friction angle ($\phi$), density ($\rho$), and average diameter of particles ($d_{50}$). It is noted that the bead particles were identical.

**Table 1. Properties of test materials**

| | $\phi$ (deg) | $\rho$ $(kg/m^3)$ | $d_{50}$ (cm) |
|---|---|---|---|
| Rockfills | 41.3 | 1.58 | 0.9 |
| Loose Beads | 30.7 | 0.97 | 1.2 |
| Dense Beads | 37.4 | 1.04 | 1.2 |

## 3- Observations and discussion

Regarding authors' definition, the stable arch which would be formed over a trapdoor with maximum possible width $W_{cr}$ (about 4.7 to 8.67 times $d_{50}$ based on $\phi$ and $\theta$ values), is considered as "critical arch". It means that if trapdoor width exceeds $W_{cr}$, then arch formation is impossible. This step is considered as "failure threshold", and at the next one, when the trapdoor width becomes wider than $W_{cr}$, the observed events will be attributed to "after failure". The observations imply that the arch dimensions get larger with increasing the trapdoor width. However, the height of the critical arch is reduced compared with the previous step. The reason may depend on the discharge rate of particles, interlocking of grains more rapidly, and establishing a volume balance between discharged materials with those inside the box along with the empty space limited to arch boundary and trapdoor at this step.

The results indicate that after failure of the stable arch, left-over particles inside the test box are in a symmetric form on both the horizontal rails. Moreover, each mass arrangement remains nearly the same as the initial array. Therefore, each one can be described as the "stagnant mass" of materials (Fig. 3).

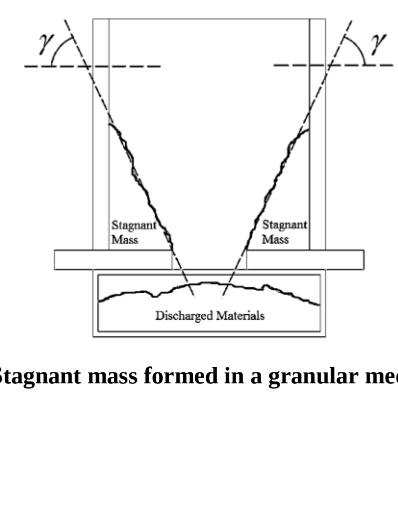


**Fig. 3 Stagnant mass formed in a granular medium and its direction with respect to horizon**

The angle of stagnant mass with respect to the horizontal ($\gamma$) may be derived from internal friction angle ($\phi$) of the granular materials as well as the main base angle ($\theta$) by the following expression:

$$\gamma \approx \left(45^\circ + \frac{\phi}{2}\right) \cdot \left(\frac{\theta}{32.6}\right)^{0.14} \tag{1}$$

## 4- Conclusion

The developed trapdoor apparatus can be applied to study the generation of arching which means the formation of a stable arch in cohesionless materials. In addition, the geometric characteristics can be studied well. The most outcomes of the present study include:

1) The maximum possible trapdoor width at which an arch-like formation can be generated is about 4.7 to 8.7 times the mean particle size of the granular materials. This value corresponds to the internal friction angle of the particles. This arch is referred to as “Critical Arch”.
2) Although the width of the critical arch is the biggest among all possible arch-like formations, the arch height is not necessarily the biggest. For the height of the arches, it was seen that the height of all arches was increased as the width increases with the exception of the critical arch. The height of the critical arch was decreased with respect to the previous possible generation of arch.
3) After the collapse of the critical height, the particle flow would be continued until a stagnant part of the medium would remain with a stable slope. The stagnant slope angle is dependent on the internal friction angle of the particles.