Facade Damage Assessment of the Buildings in Bam, Iran 2003 and Kermanshah, Iran 2017 Earthquakes

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Abstract. One of the essential factors in buildings frontage is the continuity of the structural and building envelope parts. In this investigation, a comparison was made between Bam and Kermanshah earthquakes. A strong earthquake (magnitude 6.6) struck the city of Bam in southeast Iran on 26 December 2003, and similarly, another strong earthquake struck the city of Kermanshah (magnitude 7.3) in Iran on 12 November 2017. Damage in the facades of the buildings was a clear contributor to the overall building damage. This paper presents the damage assessment of the different facade systems from multi-story buildings in Bam and Kermanshah, Iran. The survey covers the buildings greater than three stories in height, excluding most unreinforced masonry facades. As far as a building can have more than one facade system, any facade systems are evaluated individually. Observation of facade damage is discussed and is presented in terms of its performance level.

1. Introduction
On Friday, December 26, 2003, at 1:56:56 GMT (5:26:56 local time), a powerful earthquake struck Bam, a city located in southeastern Iran. The magnitude is 6.6 by USGS1, killing more than 40,000 and injuring more than 25,000 people in Bam Township (Fig 1a). The depth of this earthquake is estimated to be about 7 km. The epicenter of this earthquake is located at N29.2 E58.4 coordinates, as reported by the Institute of Geophysics of Tehran University. The construction quality in this area of Iran is generally poor, particularly in small towns and villages. The buildings in these regions are highly vulnerable even to moderate earthquakes, and most of them completely collapse when subjected to these excitations [5].

On Sunday, November 12, 2017, at 21:48 local time, a powerful earthquake struck Kermanshah, a city located northwest of Iran. The magnitude is 7.3 by USGS1, killing more than 630 and injuring more than 8100 people in Kermanshah Township (Fig 1b). The depth of this earthquake is estimated to be about 19 km. It should be noted that the seismic zones are classified into four categories (Low, Moderate, High, and very high-risk categories), and Bam is in high risk, and Kermanshah is in a very high-risk area. These earthquakes occurred due to the stresses generated by the motion of the Arabian plate northward against the Eurasian plate (Fig 2). Deformation of the earth’s crust in response to the plate motion takes place in a broad zone that spans the entire width of Iran and extends into
Turkmenistan. Earthquakes occur due to both reverse faulting and strike-slip faulting within the zone of deformation [1-6].

However, the seismic performance of structural elements had been widely investigated in the literature, and a lack of information regarding the damage assessments of facades performance is one of the main topics in the construction industry [7-9]. Moreover, the central part of the previous studies focused on the structural behavior and lateral load systems. Limited published studies are dealing with damage assessments of facades and the connection of the structural elements.

This research aims to investigate the damage assessments of different types of facades during seismic actions. The facades and structural response throughout the earthquake were evaluated based on Bam and Kermanshah earthquakes. For this purpose, currently used different types of facades for buildings in Iran were considered for better understanding the behavior of the facades during the earthquake.

![Figure 1. The geographic location of Bam and Kermanshah on the map.](image1)

![Figure 2. Plate tectonic map of Iran region.](image2)

2. Facade technology in Iran
Facade systems can be classified into the following types; composite facade, glass facade, bayramix facade claddings, Stone facade, Ceramics facade, and Brick facade. The simplest way to differentiate between the two types is to construct in dry and wet conditions, while all of them are attached externally to the primary structure. Types of facades used in the existing buildings in Iran are illustrated in Fig 3.
2.1. Composite facade
Composites are unique types of materials that are formed by two or more substances, so the combined substance has more strength and durability than the individual ingredients. Today, composites are typically used for exterior building facades. The composites consist of two layers of aluminum and a core of plastic or mineral fillers located between these two layers. The properties of composites are generally better than any of their ingredients. It is noteworthy that various ingredients improve performance. Although composites are weak in terms of flexibility, however, we can mention the lightweight, ease of assembling, and maintenance as their advantages. Composite facades used in Bam buildings in Iran are illustrated in Fig 4.

![Composite facade failure during the Bam 2003](image)

**Figure 4.** Composite facades failures during the Bam 2003.

2.2. Glass facade
Glass facades have been used since the modern architecture era as the buildings cover. They cause lots of problems for residents as the result of their low thickness as well as lack of thermal resistance. Glass facades used in Bam and Kermanshah buildings in Iran are illustrated in Fig 5.

![Glass facade failure during the Bam 2003](image)

**Figure 5.** Glass facade failures during the Bam 2003.
2.3. **Bayramix facade**

Bayramix is a decorative cover that is utilized as an interior or exterior facade. This product is applicable on painted walls, stone, cement walls, wood, cardboard, plastic, metal, and glass. A Turkish construction group used Bayramix for the first time in 1993, and it was presented to the world. The most recent product is in the form of mortar, and it is a mixture of granite grains and marble with different colors, numerous grading, natural and artificial resins, and other additives. Bayramix is not applicable on greasy, dusty, rugged, wet surfaces or in stormy or dusty weather. Although this type of facade has some advantages; however, it has not been welcomed by Iranian engineers and construction contractors because this type of facade is inconsistent with their cultural context and tendencies. So it will lose its beauty and effect in a short time. Bayramix facades used in Bam and Kermanshah buildings in Iran are illustrated in Fig 6.

![Bayramix facades failures during the Bam 2003 and Kermanshah 2017 earthquakes.](image)

**Figure 5.** Glass facades failures during the Bam 2003 and Kermanshah 2017 earthquakes.

![Bayramix facades failures during the Bam 2003 and Kermanshah 2017 earthquakes.](image)

**Figure 6.** Bayramix facades failures during the Bam 2003 and Kermanshah 2017 earthquakes.
2.4. Stone facade

Two groups of natural stones are executable in the facade; limestones and igneous stones. Limestone is not usually durable due to the existence of strands. On the other side, low water absorption and poor adhesion are the main igneous stones problems. Moreover, the facade is significant as it is exposed to weather conditions. The stones used for the facade should have particular features to sustain against these natural factors. Stone facades used in Bam and Kermanshah buildings in Iran are illustrated in Fig 7.

![Stone facades failures during the Bam 2003 and Kermanshah 2017 earthquakes.](image)

**Figure 7.** Stone facades failures during the Bam 2003 and Kermanshah 2017 earthquakes.

2.5. Brick facade

The brick facade is the other type of frontage, and it is divided into two groups; clay bricks and chili bricks. Brick facades have some benefits, such as beauty, variety, and color stability. In addition, it plays the role of cryogenic and thermal insulation because of the low heat transfer coefficient. As a result, brick building facades prevent wasting heating and cooling energy. According to their color and material, brick facades cause reflection of the heat in summer and absorb solar energy in winter. Brick facades used in Bam and Kermanshah buildings in Iran are illustrated in Fig 8.

![Brick facades failures during the Bam 2003 and Kermanshah 2017 earthquakes.](image)

**Figure 8.** Brick facades failures during the Bam 2003 and Kermanshah 2017 earthquakes.
3. General behavior of the systems
The old facades like brick facades and stone that employ the wet material for pasting the facades could not present an acceptable performance during the seismic actions, even during the service period. In the case of seismic categories, facade damage belongs to limited damage during the seismic actions. The surveying of the different facades showed the weaknesses of traditional types like brick and stone facades. The new methods like glass and composite that can be connected to the structural elements had better performance. To produce accurate results that benefit the construction industry, the performance of the facades should be evaluated in detail. Therefore, the industry needs to use a proper system that can have a minimal displacement or facade system that can accommodate a certain level of displacements during the earthquake. However, the composite is primarily typical in business and commercial buildings because they want to be different and make the building more exciting, or a city sign, stone, or brick facades are typically used in residential buildings to protect the privacy and save energy and money. Among the factors for selecting the facades, price and general view of the facades are more critical than others parameters. Nevertheless, the parameters of the seismic performance should evaluate for any of the existing facades. In the case of fixing methods after the earthquake, traditional methods are more complex than new technics since wet paste materials have been used.

4. Conclusion
According to the reasons mentioned above, the conclusions are summarized below:
- It is noticeable that the seismic behavior of the facades of the building should be one of the main factors in selecting the type of facade.
- The traditional and old methods of facades like brick facades and stone could not present an acceptable performance during the seismic actions in Bam 2003 and Kermanshah 2017, and generally, the damages cannot be relatively easy to fix.
- Earthquake damage to facade systems undoubtedly poses a significant threat to life. The economic implication from facade damage is also significant due to business downtime and repair costs.
- Although facade damage belongs to limited damage during the seismic actions, surveying the different types of facades showed the weaknesses of traditional types like brick and stone facades.
- In fixing schema after the seismic actions, traditional methods are more complex since wet paste materials have been used and repair of new technics is relatively easy.
- In order to reduce damage to facade systems in the future, both technical and political issues need to be addressed. Improvements are required to better understand the behavior of many facade systems and whether the methods used to isolate them are satisfactory. Design guidelines are required for both designers and installers of facade systems. Communicating common errors that should be avoided is also essential.

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