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SEISMIC PERFORMANCE OF CONCRETE STRUCTURES IN THE 2017 KERMANSHAH EARTHQUAKE IN IRAN

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ABSTRACT

The M_w 7.3 Kermanshah earthquake struck west part of Iran on the 12 November of 2017. This event had more than 500 aftershocks with magnitude between 1.8 to 4.7. The epicentre of this event was located at 34.88°N and 45.84°E near the Iran–Iraq border with a depth of 23 km. During Kermanshah earthquake more than 400 People died and many thousands were injured. This paper presents preliminary field observations on the performance of more than 600 reinforced concrete (RC) buildings. About 60% of buildings performed well, but unfortunately the rest of them have been damaged severely which leads to loss of many lives. The critical weaknesses of these structures are soft storey (weak column-strong beam), short columns, torsional behaviour, non-structural failure and poor site constructions.

Key words: Kermanshah Earthquake- RC structural behaviour- Critical weakness

INTRODUCTION

On Sunday November 12, 2017, at 18:18:16 UTC, (21:48:16 local time), a strong earthquake with Mw7.3 occurred in the west region of Iran. The earthquake was centred approximately 10 Km from Gele and 37 Km north-west of Sarpol-e Zahab city of Kermanshah province, located on the border of Iran and Iraq, as shown in Figure 1. This event that continued for 30 seconds, was felt in an extended area in Iran, Mesopotamia, the Caucasus, eastern Turkey, Iraq and Syria. The Iranian Seismological Centre Institute of Geophysics (IRSC), University of Tehran (IRSC ,2016) reported more than 500 aftershocks. Figure 1 shows the geological location of the main shock and aftershocks. The largest magnitude of this earthquake's aftershock sequence was 4.8, which occurred November 13th.

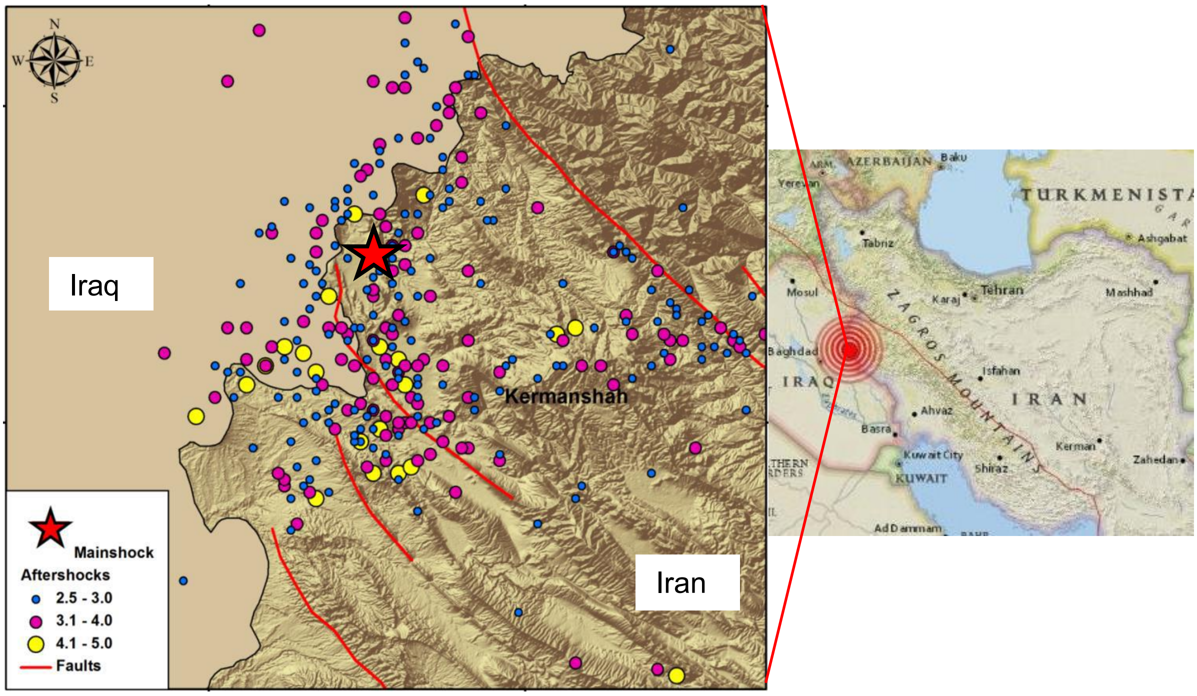

Figure 1. The geological location of Kermanshah earthquake of November 2017, Iran (Farajpour et al. 2017).

The Mw7.3 main shock has been recorded by 98 stations of the Iran Strong Motion Network (ISMN). Figure 2 shows the dispersion map of maximum recorded acceleration calculated by interpolation at the accelerometer stations of the research centre. The maximum acceleration was recorded at the Sarpol-e Zahab station (point A) with 0.68g. The pulse directivity phenomenon occurred at the Sarpol-e Zahab station with a maximum acceleration in this area more than twice of the other stations with same distance from the centre of earthquake. Figure 3 shows the acceleration and velocity were recorded at the Sarepol-e Zahab station.

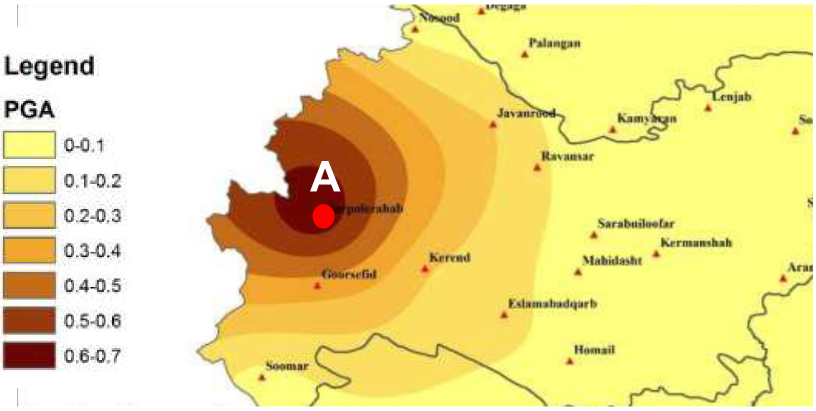

Figure 2. Dispersion map of maximum recorded acceleration.

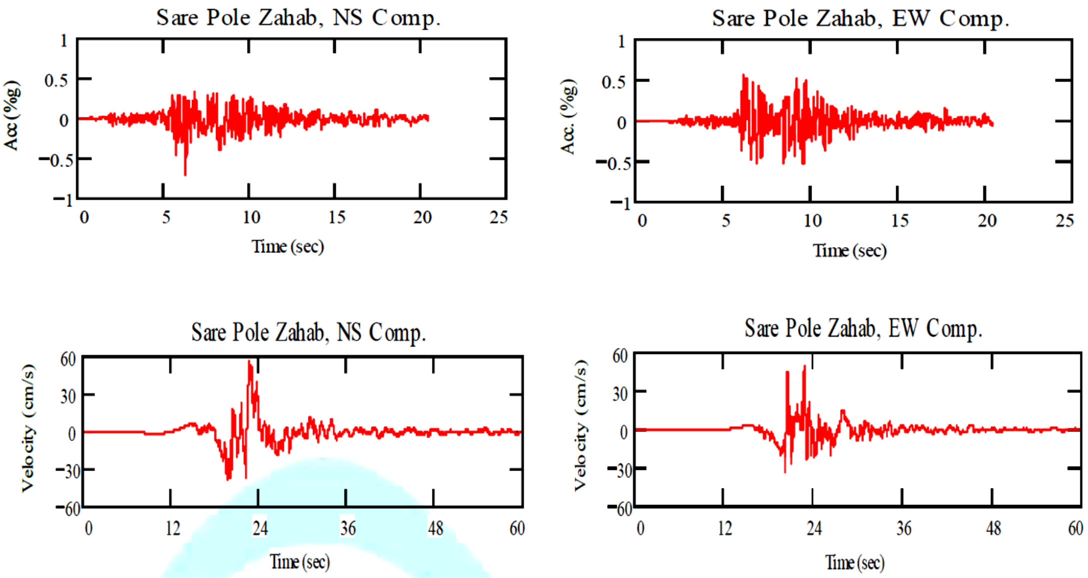

Figure 3. Acceleration and velocity recorded at Sarepol-e Zahab station.

As a result of the Kermanshah earthquake 400 people died and many thousands were injured. Table 1 shows the population, number of loss of life, and maximum recorded acceleration of all main cities in the Kermanshah province.

Table 1. the population, No. of dead and maximum acceleration in different city in Kermanshah Province

Region	**Population**	**Loss of life**	**Maximum acceleration (gal)**
Sarepol-e Zahab	85342	317	684
Eslam abad gharb	140876	23	123
Selas babajani	35219	15	196
Javan rod	75169	3	208
Karand gharb	7972	14	261
Gor sefid	811	-	309
Ravansar	47657	-	121
Kermanshah	1952434	1	124
Ghasre shirin	23929	28	-
Azgale	939	-	-
Rafi	522	-	-

This paper describes the immediate observations of damage to RC buildings from the Kermanshah earthquake. Some preliminary lessons are highlighted and discussed in light of the observed buildings performance. Typical damage patterns of various configurations and lateral resisting systems of RC construction are presented.

CRITICAL WEAKNESS OF REINFORCED CONCRETE (RC) BUILDING

The critical weaknesses of reinforced concrete structures observed from this earthquake were weak column-strong beam (soft-story collapse), short columns, torsional behaviour, poor site constructions and non-structural element failure.

Soft story due to weak column-strong beam

Modern codes of practice apply the sound principles of capacity design to design earthquake resistant structures. For this purpose, a hierarchic formation of plastic hinges is enforced by design, to create the most desirable and stable energy dissipating mechanism. In this context, it is widely recognised that the most desirable location for plastic hinges in moment resisting frames is within the beams adjustment the column face with the total column moment strength larger than the total beam moment strength to guarantee that beams yield before columns. Allowing the column member to remain elastic during strong earthquake. So, it can provide stability and strength of the stories above.

According to the Iranian Standard, for high ductility structures, the flexural capacity of the column should be 20% more than flexural capacity of the beams. However, in the standard this is not specifically required for structures with nominal ductility. This type of structures covers most of the residential buildings. Therefore, in many residential RC frame buildings, column plastic mechanism, were observed instead of beam plastic mechanism during the earthquake, as shown in Figure 4.

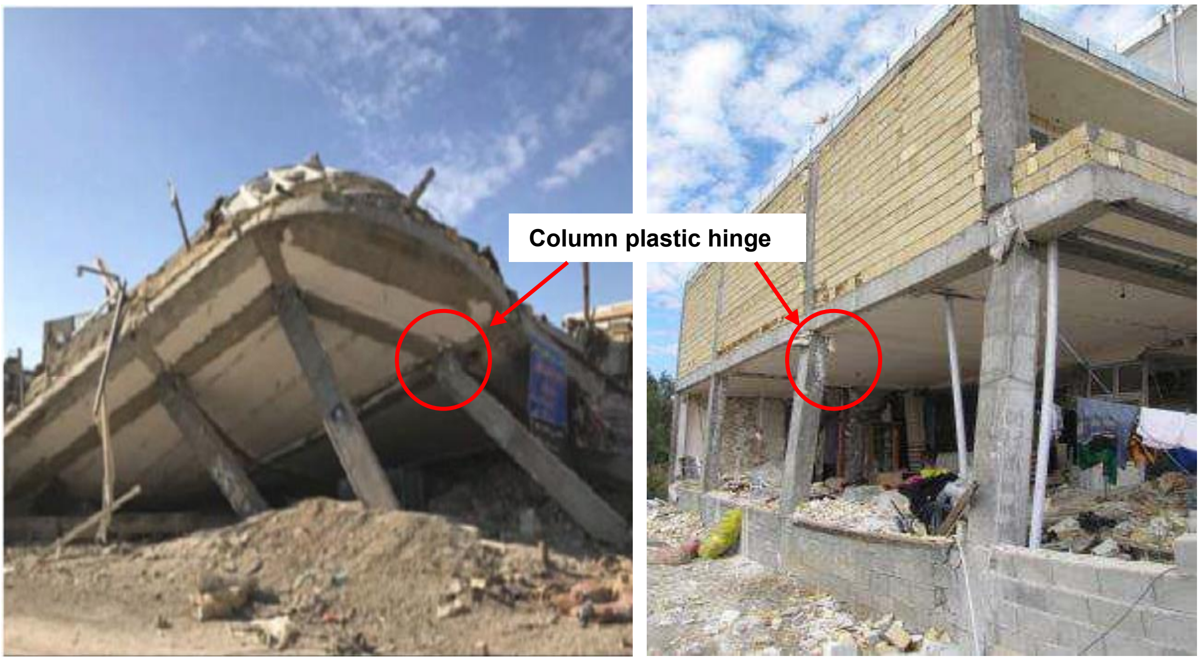

Figure 4. Soft story due to the weak column-strong beam

Short columns

Short columns failure can happen when the effective clear shear span of the columns is reduced due to presence of masonry, concrete infill or stiff non-structural facades. Therefore, non-structural components such as partition walls and facades in buildings shall be detailed in such a way that they do not impose any restraint for the displacement of structural systems during an earthquake. Otherwise, their interaction with structural system shall be considered (Iranian Standard 2800 section 1-5-6).

However, a common observation was in the design of the buildings in this region that this has not been considered. This resulted in short column failures and irreparable damage such as building twist, weak floors, and local damage of structural elements, as shown in Figure 5.

Figure 5. Short column failure due to presence of masonry infill

Torsional failure

One of the advantages of using moment frame systems is the ability to provide openings on the ground floor for commercial or parking reasons. Therefore, in this story the number of interior walls are usually less than other stories and resulting structural irregularity. Horizontal and vertical plan irregularity is one of the main reasons for torsion failure in the many observed high-rise commercial unit with parking on the ground floor, as shown in Figure 6.

Figure 6. Torsion Failure

Poor condition concrete

One of the key factors to providing reliable shear capacity is the concrete strength should be not less than 20 MPa for structures with regular ductility (Iran Concrete code- Guideline 9-section 1-2-1-9). In most of the collapse or damaged buildings during this earthquake, brittle failure due to poor condition and quality of concrete (concrete without sand, grains or discrete aggregate) has been observed. Figure 7 shows some sample of poor concrete that was used in buildings of this region. Figure 8 shows some observed brittle failure of RC building due to poor condition quality of concrete.

Figure 7. concrete without sand, grains or discrete aggregate

Figure 8. Shear failure in column and shear wall and soft story because of poor quality concrete.

Inappropriate concrete cover and inadequate anchorage details

Insufficient or excessive thickness of concrete cover have been observed in some of the buildings. Increasing the thickness of the coating cause concentrating the stress and covers completely cut off from the column. A large part of the section capacity is lost at the first cracking point due to loss of the concrete cover because of either insufficient or excessive cover.

Figure 9. a) Insufficient concrete cover, b) excessive column concrete cover and spalling of concrete cover.

Also, in some observed column failures, the stirrup hook was bent 90° instead of 135°. Therefore, after losing the cover these hooks opened and caused dramatic column failure, as shown in Figure 10.

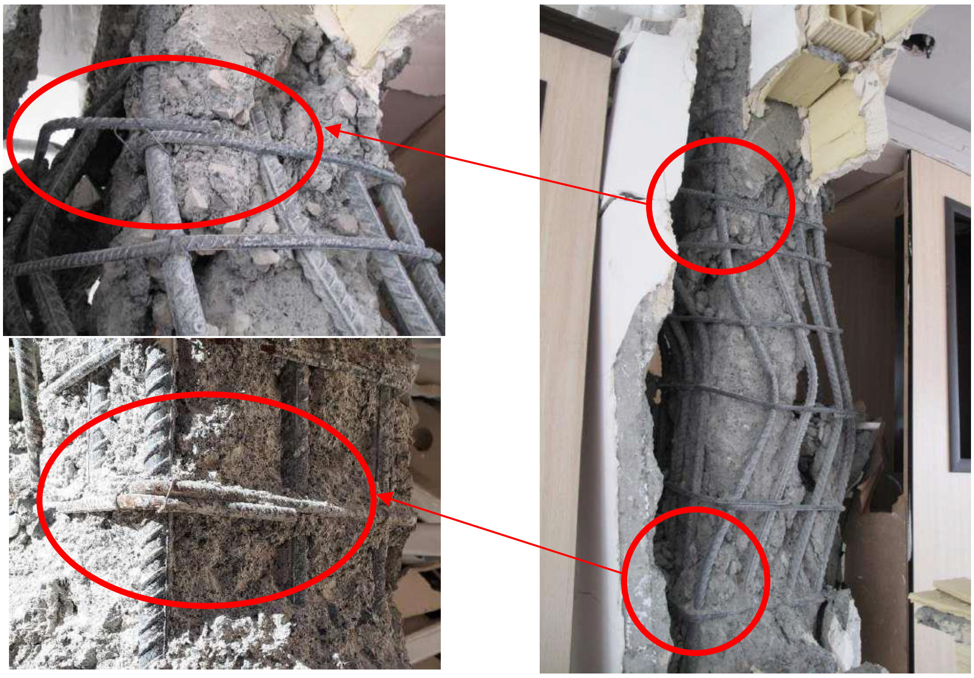

Figure 10. Inadequate anchorage detail in column

Insufficient lap splice and development length

The lap splice length should be sufficient to create a bond as if there was no break and the run is “continuous” to transfer tension and compression. With insufficient lap lengths, the capacity of the lap quickly degrades and within one cyclic of loading the lap splice may be assumed to have failed. It worth mentioning that, the poor concrete strength condition of some structures magnified failures due to insufficient lap splice and development length, as shown in Figure 11.

Figure 11. Insufficient lap splice in column

Non-structural failure

Poor performance of non-structural elements including infill cladding, non-structural walls, facades and suspended celling, were observed in most of the buildings. Even when structural damage was limited or negligible, the non-structural damage was the main contributor of losses and downtime for the majority of the RC buildings. Figure 12 shows non-structural failure of 24 residential 7-story reinforcement concrete buildings at Shirodi development.

The damaging earthquake has highlighted many instances of poor performance of non-structural elements, particularly in multi-storey buildings. While primary and secondary structural elements are designed and detailed as part of the structural engineering design of a building, non-structural elements can be overlooked or poorly managed during the design, procurement, or construction phases of the project. Careful detailing is required for non-structural elements so they can resist earthquake actions. Critical details, such as connections, restraints and, where required, flexible elements and/or separations should be identified and documented.

Figure 12. Collapse of facade, infill panel and non-structural walls of Shirodi development.

CONCLUSION

This paper presents preliminary field observations on the performance of reinforced concrete buildings under 7.3 magnitude Kermanshah earthquake on 12 November 2017, in Iran. Typical observed damage pattern and structural weakness were:

- Strong beam weak column behaviour and damage was observed in nominally ductile frames due no specific capacity design reequipments in the Iran code for this,
- Short column damage due to masonry infill detailed without appropriate seismic gaps,
- Torsion failure and ground floor soft storey collapse due to vertical and horizontal irregularity due to placement of non-structural infill walls,
- Unreliable behaviour of concrete members in shear and compression due to weak and poor condition concrete,
- Inadequate and/or excessive concrete cover causing unreliable behaviour of concrete sections,
- Brittle failure of columns due to 90° stirrup hooks which have inadequate anchorage into the concrete core,

- Failure of lap splices due to inadequate splice length and low strength and poor concrete,
- Significant damage to non-structural infill and cladding in multi-storey buildings due to inadequate separation from the primary structure.

And any other things that apply to the lessons learned from the earthquakes.

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