Why are Open-Ground Storey Buildings vulnerable in Earthquakes?

Basic Features

Reinforced concrete (RC) frame buildings are becoming increasingly common in urban India. Many such buildings constructed in recent times have a special feature – the ground storey is left *open* for the purpose of parking (Figure 1), *i.e.,* columns in the ground storey do not have any partition walls (of either masonry or RC) between them. Such buildings are often called *open ground storey buildings* or *buildings on stilts*.

Figure 1: Ground storeys of reinforced concrete buildings are left open to facilitate parking – *this is common in urban areas in India.*

An open ground storey building, having *only columns* in the ground storey and *both partition walls and columns* in the upper storeys, have two distinct characteristics, namely:

(a) It is relatively *flexible* in the ground storey, *i.e.,* the relative horizontal displacement it undergoes in the ground storey is much larger than what each of the storeys above it does. This flexible ground storey is also called *soft storey*.

(b) It is relatively *weak* in ground storey, *i.e.,* the total horizontal earthquake force it can carry in the ground storey is significantly smaller than what each of the storeys above it can carry. Thus, the open ground storey may also be a *weak storey*.

Often, open ground storey buildings are called *soft storey buildings*, even though their ground storey may be *soft and weak*. Generally, the soft or weak storey usually exists at the ground storey level, but it could be at any other storey level too.

Earthquake Behaviour

Open ground storey buildings have consistently shown poor performance during past earthquakes across the world (for example during *1999 Turkey*, *1999 Taiwan* and *2003 Algeria* earthquakes); a significant number of them have collapsed. A large number of buildings with open ground storey have been built in India in recent years. For instance, the city of Ahmedabad alone has about 25,000 *five-storey* buildings and about 1,500 *eleven-storey* buildings; majority of them have open ground storeys. Further, a huge number of similarly designed and constructed buildings exist in the various towns and cities situated in moderate to severe seismic zones (namely III, IV and V) of the country. The collapse of more than a hundred RC frame buildings with open ground storeys at Ahmedabad (~225km away from epicenter) during the 2001 Bhuj earthquake has emphasised that such buildings are *extremely* vulnerable under earthquake shaking.

The presence of walls in upper storeys makes them much stiffer than the open ground storey. Thus, the upper storeys move almost together as a single block, and most of the horizontal displacement of the building occurs in the soft ground storey itself. In common language, this type of buildings can be explained as a building on chopsticks. Thus, such buildings swing *back-and-forth* like *inverted pendulums* during earthquake shaking (Figure 2a), and the columns in the open ground storey are severely stressed (Figure 2b). If the columns are weak (do not have the required strength to resist these high stresses) or if they do not have adequate ductility (See *IIT-BMTPC Earthquake Tip 9*), they may be severely damaged (Figure 3a) which may even lead to collapse of the building (Figure 3b).

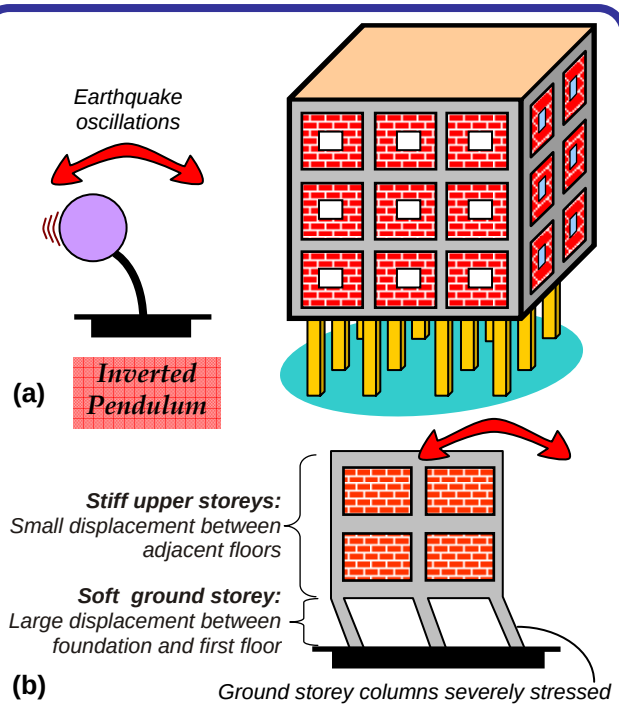

Figure 2: Upper storeys of open ground storey buildings move together as a single block – *such buildings are like inverted pendulums.*

Photo Courtesy: The EERI Annotated Slide Set CD, Earthquake Engineering Research Institute, Oakland (CA), USA, 1998.

(a) 1971 San Fernando Earthquake

(b) 2001 Bhuj Earthquake

Figure 3: Consequences of open ground storeys in RC frame buildings – *severe damage to ground storey columns and building collapses.*

The Problem

Open ground storey buildings are *inherently poor* systems with sudden drop in stiffness and strength in the ground storey. In the current practice, *stiff* masonry walls (Figure 4a) are neglected and only *bare frames* are considered in design calculations (Figure 4b). Thus, the inverted pendulum effect is not captured in design.

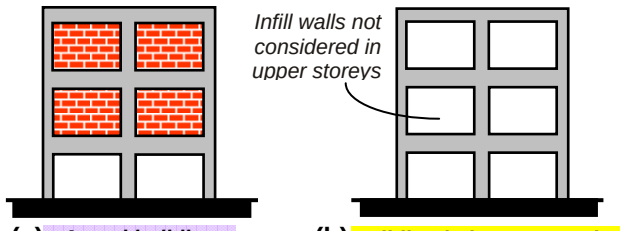

Figure 4: Open ground storey building – *assumptions made in current design practice are not consistent with the actual structure.*

Improved design strategies

After the collapses of RC buildings in 2001 Bhuj earthquake, the Indian Seismic Code IS:1893 (Part 1) - 2002 has included special design provisions related to soft storey buildings. Firstly, it specifies when a building should be considered as a *soft* and a *weak storey building*. Secondly, it specifies higher design forces for the soft storey as compared to the rest of the structure. The Code suggests that the forces in the columns, beams and shear walls (if any) under the action of seismic loads specified in the code, may be obtained by considering the *bare frame* building (without any infills) (Figure 4b). However, beams and columns *in the open ground storey* are required to be designed for 2.5 times the forces obtained from this bare frame analysis.

For all *new RC frame buildings*, the best option is to avoid such sudden and large decrease in stiffness and/or strength in any storey; it would be ideal to build walls (either masonry or RC walls) in the ground storey also (Figure 5). Designers can avoid dangerous effects of flexible and weak ground storeys by ensuring that too many walls are not discontinued in the ground storey, *i.e.,* the drop in stiffness and strength in the ground storey level is not abrupt due to the absence of infill walls.

The *existing open ground storey buildings* need to be strengthened suitably so as to prevent them from collapsing during strong earthquake shaking. The owners should seek the services of qualified structural engineers who are able to suggest appropriate solutions to increase seismic safety of these buildings.

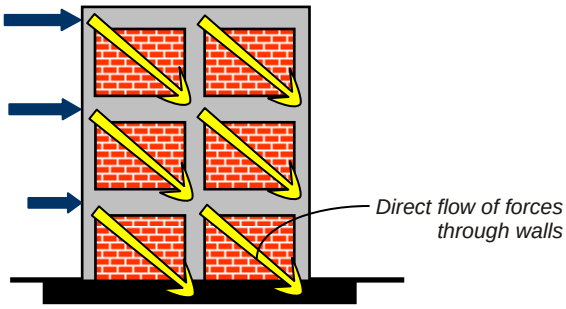

Figure 5: Avoiding open ground storey problem – *continuity of walls in ground storey is preferred.*

Related IITK - BMTPC Earthquake Tip

Tip 6: How Architectural Features Affect Buildings During Earthquakes?

Tip17: What are the Earthquake Effects on Reinforced Concrete Buildings?

Reading Material

IS 1893(Part 1) (2002), "*Indian Standard Code of Practice for Criteria for Design of Earthquake Resistant Structures*," Bureau of Indian Standards, New Delhi

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