IITK - BMTPC

Earthquake Tip 9

Learning Earthquake Design and Construction

How to make Buildings ductile for Good Seismic Performance?

Construction Materials

In India, most non-urban buildings are made in masonry. In the plains, masonry is generally made of burnt clay bricks and cement mortar. However, in hilly areas, stone masonry with mud mortar is more prevalent; but, in recent times, it is being replaced with cement mortar. Masonry can carry loads that cause *compression* (*i.e.*, pressing together), but can hardly take load that causes *tension* (*i.e.*, pulling apart) (Figure 1).

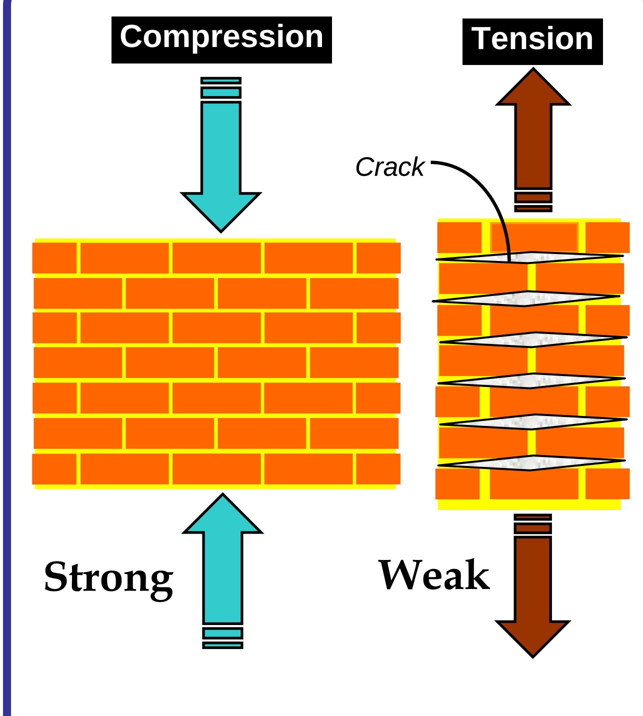

Figure 1: Masonry is strong in compression but weak in tension.

Concrete is another material that has been popularly used in building construction particularly over the last four decades. Cement concrete is made of crushed stone pieces (called *aggregate*), sand, cement and water mixed in appropriate proportions. Concrete is much stronger than masonry under *compressive* loads, but again its behaviour in tension is poor. The properties of concrete critically depend on the amount of water used in making concrete; too much and too little water, both can cause havoc. In general, both masonry and concrete are brittle, and fail suddenly.

Steel is used in masonry and concrete buildings as reinforcement bars of diameter ranging from 6mm to 40mm. Reinforcing steel can carry both tensile and compressive loads. Moreover, steel is a *ductile material*. This important property of ductility enables steel bars to undergo large elongation before breaking.

Concrete is used in buildings along with steel reinforcement bars. This composite material is called *reinforced cement concrete* or simply *reinforced concrete* (RC). The amount and location of steel in a member should be such that the failure of the member is by steel reaching its strength in tension before concrete reaches its strength in compression. This type of failure is *ductile failure*, and hence is preferred over a failure where concrete fails first in compression. Therefore, contrary to common thinking, providing too much steel in RC buildings can be harmful even!!

Capacity Design Concept

Let us take two bars of same length and cross-sectional area - one made of a ductile material and another of a brittle material. Now, pull these two bars until they break!! You will notice that the ductile bar elongates by a large amount before it breaks, while the brittle bar breaks suddenly on reaching its maximum strength at a relatively small elongation (Figure 2). Amongst the materials used in building construction, steel is *ductile*, while masonry and concrete are *brittle*.

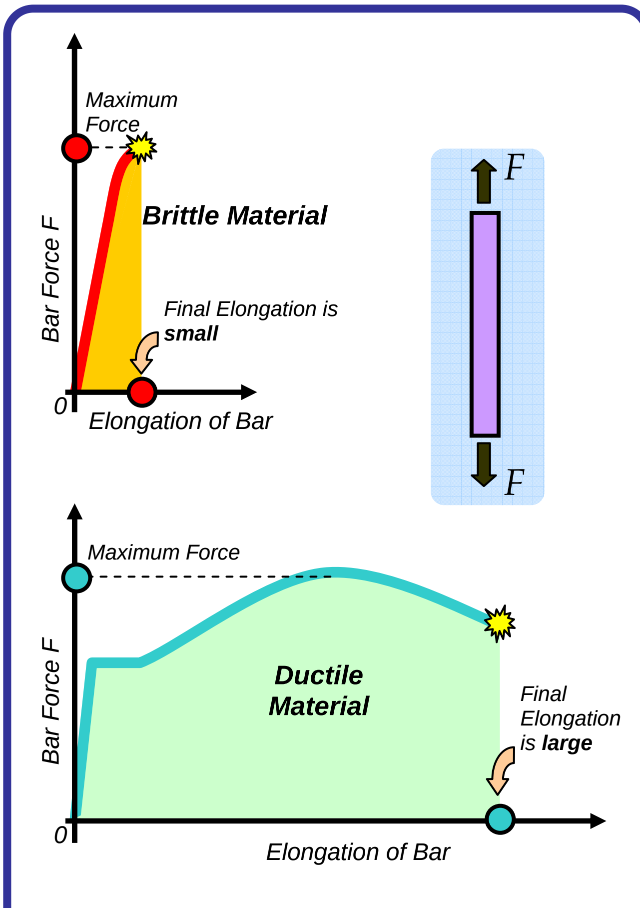

Figure 2: Tension Test on Materials – ***ductile versus brittle materials*****.**

Now, let us make a chain with links made of *brittle* and *ductile* materials (Figure 3). Each of these links will fail just like the bars shown in Figure 2. Now, hold the last link at either end of the chain and apply a force *F*. Since the same force *F* is being transferred through all the links, the force in each link is the same, *i.e., F*. As more and more force is applied, eventually the chain will break when the *weakest link* in it breaks. If the ductile link is the *weak* one (*i.e.*, its capacity to take load is less), then the chain will show large final elongation. Instead, if the brittle link is the weak one, then the chain will fail suddenly and show small final elongation. Therefore, if we want to have such a *ductile* chain, we have to make the ductile link to be the *weakest* link.

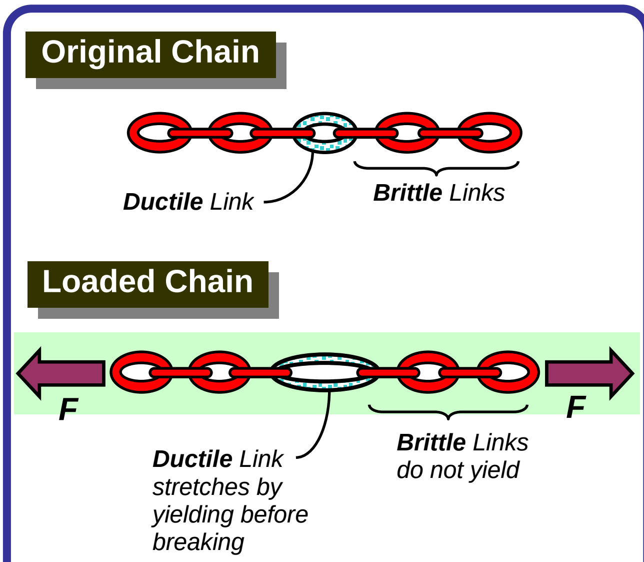

Figure 3: Ductile chain design.

Earthquake-Resistant Design of Buildings

Buildings should be designed like the ductile chain. For example, consider the common urban residential apartment construction - the multi-storey building made of reinforced concrete. It consists of horizontal and vertical members, namely *beams* and *columns*. The seismic inertia forces generated at its floor levels are transferred through the various *beams* and *columns* to the ground. The correct building components need to be made ductile. The failure of a column can affect the stability of the whole building, but the failure of a beam causes localized effect. Therefore, it is better to make *beams* to be the ductile weak links than *columns*. This method of designing RC buildings is called the *strong-column weak-beam* design method (Figure 4).

By using the *routine* design codes (meant for design against non-earthquake effects), designers may not be able to achieve a ductile structure. Special design provisions are required to help designers improve the ductility of the structure. Such provisions are usually put together in the form of a special *seismic* design code, *e.g.,* IS:13920-1993 for RC structures. These codes also ensure that adequate ductility is provided in the members where damage is expected.

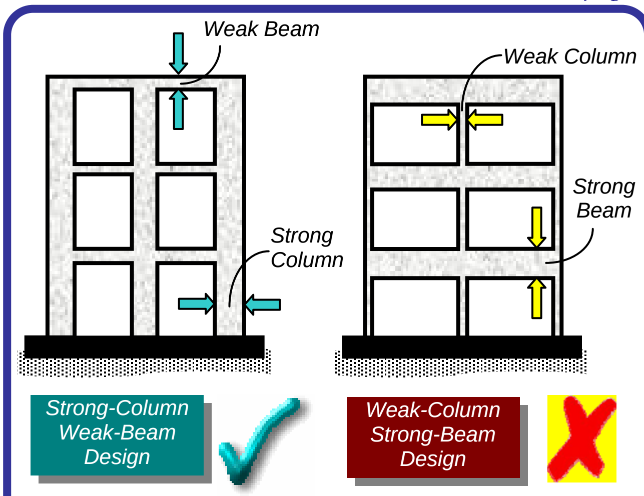

Figure 4: Reinforced Concrete Building Design: *the beams must be the weakest links and not the columns – this can be achieved by appropriately sizing the members and providing correct amount of steel reinforcement in them.*

Quality Control in Construction

The capacity design concept in earthquake-resistant design of buildings will fail if the strengths of the brittle links fall below their minimum assured values. The strength of brittle construction materials, like masonry and concrete, is highly sensitive to the quality of construction materials, workmanship, supervision, and construction methods. Similarly, special care is needed in construction to ensure that the elements meant to be ductile are indeed provided with features that give adequate ductility. Thus, strict adherence to prescribed standards of construction materials and construction processes is essential in assuring an earthquake-resistant building. Regular testing of construction materials at qualified laboratories (at site or away), periodic training of workmen at professional training houses, and on-site evaluation of the technical work are elements of good quality control.

Reading Material

Paulay,T., and Priestley,M.J.N., (1992), *Seismic Design of Reinforced Concrete Buildings and Masonry*, John Wiley, USA

Mazzolani,F.M., and Piluso,V., (1996), *Theory and Design of Seismic-Resistant Steel Frames*, E&FN Spon, UK

Authored by:
C.V.R.Murty
Indian Institute of Technology Kanpur
Kanpur, India
Sponsored by:
Building Materials and Technology Promotion Council, New Delhi, India