Performance of RC Buildings along Hill Slopes of Himalayas during 2011 Sikkim Earthquake

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SUMMARY
Unregulated development in the Himalayan region indicates that RC frame buildings up to 9 storeys are being constructed without even designing them for gravity loads. Many features of these buildings render them vulnerable to lateral shaking, including column bases rested on ground at different heights (multi-support excitation of the building on steep hill slopes connected to the ground at least at 5 levels), and half brick masonry infill walls distributed irregularly in plan within each storey. This paper presents results of nonlinear analyses preformed on typical buildings on steep hill slopes with two possible types of column base connectivity to the ground. The paper finds RC buildings with large plan size (either in the valley direction or along road direction) vulnerable to strong seismic shaking. Only small plan buildings are most suitable for construction along steep hill slopes.

Keywords: Unanchored column footings, large column axial loads, stability of valley side columns

1. INTRODUCTION

The state of Sikkim has been adopting three dominant construction typologies, namely

(i) Traditional wood frame construction with ekra/bamboo-matting walling;
(ii) Unreinforced masonry (URM) construction with masonry units of stone, burnt clay brick or cement blocks, in no, mud or cement mortar, with NO earthquake-resistant features; and
(iii) Reinforced concrete (RC) construction with moment frame type configurations; some RC construction mimic traditional wood frame construction type.

Of the above three, the third is most prevalent throughout the hills. These RC constructions are mostly non-engineered (*i.e.,* built with no formal engineering inputs) and have emerged in the recent two decades in most towns and cities. For instance, about 14,000 RC buildings are presently standing in Gangtok, and only about 65% of these were built in past 15 years (Figure 1.1). This observation is valid uniformly for housing as well as critical and lifeline buildings and structures. RC construction across the state in general use hand-mixed concrete based on volume batching, no mechanical vibrator, no control on water-cement ratio, and inadequate curing. Such buildings are built along river slopes too (Figure 1.2). Here, the problem is compounded by high flood level that erodes the soil underneath the footings of the columns, notwithstanding the usual creeping of the cut slopes along river banks.

Figure 1.1 Skyline of Gangtok city covered with RC frame buildings in hill slopes built in last 10-15 years with no techno-legal regime in place

Figure 1.2 Housing sprawl along the Teesta river side made of reinforced concrete frames, that lack many desirable features necessary to be called earthquake resistant

2. PERFORMANCE OF RC BUILDINGS ON HILL SLOPES DURING 2011 SIKKIM EARTHQUAKE

During the 2011 Sikkim earthquake, many buildings were shaken severely and some even collapsed. For instance, the government owned ITBP campus building near Chungthang sustained large inelastic deformations in the lowest storey, even though the hill slope was shallow (Figure 2.1). Typical individual homes are small and are of single storey, with frame columns spreading along the hill slope

(Figure 2.2); even in these small building, severe damage was noticed, but this is largely attributed to poor quality of construction. In large RC buildings of 7-9 storeys along hill slopes, the common practice of completely removing masonry infill walls between the columns and providing half-brick infills on the cantilever slabs have caused significant damage. In one instance in Gangtok, there was severe damage, but no collapse (Figure 2.3). But, in another instance, three intermediate storeys collapsed (Figure 2.4a). One three storey building on hill slopes of Gangtok collapsed again due to insufficient lateral capacity to resist ground shaking (Figure 2.4b); the recorded PGA value in Gangtok was only around 0.15g [Murty *et al*, 2012].

Figure 2.1 Building by government on shallow slope constructed near Chungthang, North Sikkim, was severely shaking in the first storey during 2011 Sikkim Earthquake. RC corner column is well confined and severely distorted

Figure 2.2 RC frame supports of RC frame buildings on hill slopes are not designed with the basic effects to withstand even small as was noted during the 18September 2011 earthquake

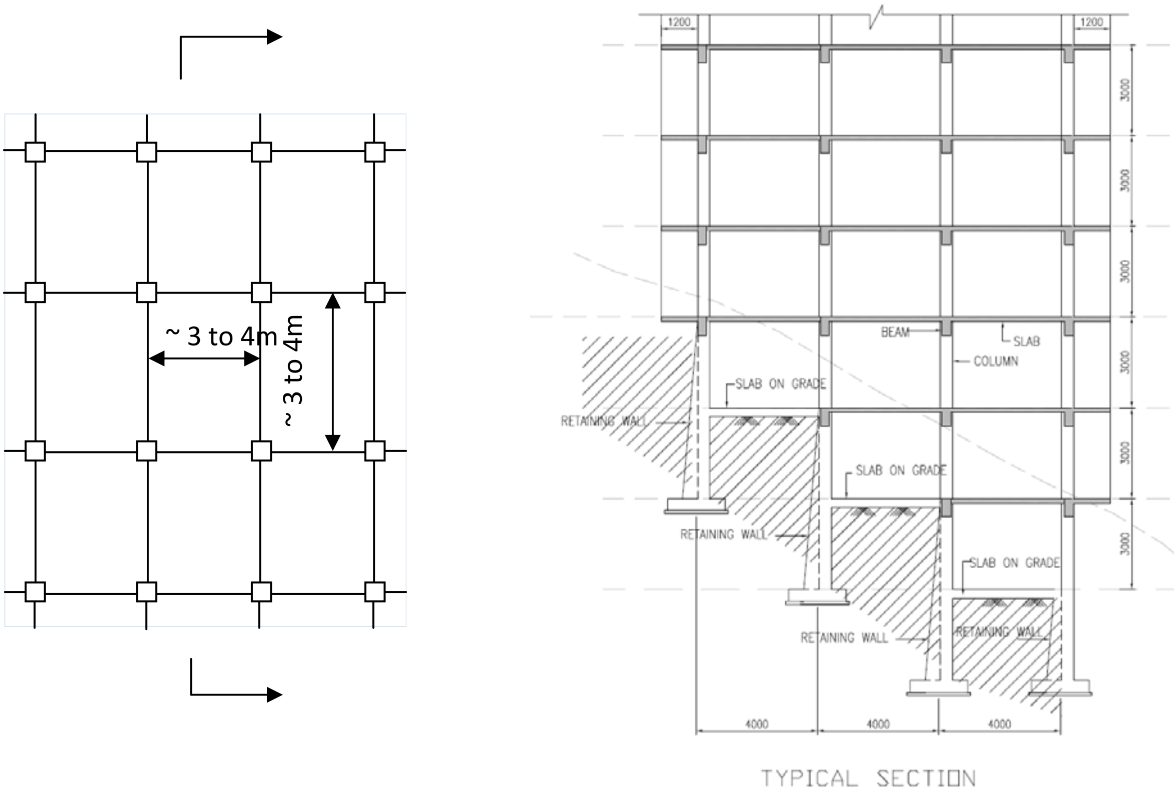
(a) **(b)**

Figure 2.3 (a) 7-storey Himachuli Building at Zero Point in Gangtok, and (b) It sustained compression failure of columns in intermediate open storey of the building at level 3 from the base

Figure 2.4 *Buildings on slope collapsed during 2011 Sikkim Earthquake:* (a) Collapse of intermediate storeys of Dzongpo House in Gangtok, and (b) Adjoining 3-storey building also collapsed

3. SEISMIC BEHAVIOUR OF BUILDING ON SLOPES

Majority of the buildings, in and around Gangtok (India), are observed to be constructed on slopes. Typical features of these buildings (Figure 3.1) include *columns of unequal lengths along the slope,* and *lack of proper foundation well embedded into the soil underneath* to provide adequate translational fixity under lateral earthquake shaking. Two basic types of fixity conditions are achieved depending on construction type and local soil/rock strata – one that provides *full translational and rotational restraints,* and the other does not. Lack of translational and rotational fixity occurs due to creep or subsidence of flexible soil along hill slope. Actual degree of fixity (translational and rotational) varies.



(a) **(b)**

Figure 3.1 Typical RC frame building along hill slopes (a) building plan, and (b) and sectional elevation [Courtesy: Alpa Sheth, Mumbai]

Consider two buildings A and B (of same width along the road direction) with three storeys above and four storeys below ground level, but with different restraints at base of columns (Figure 3.2); Building A has fixed column bases, and Building B has roller column base except underneath the tallest valley-side column. Buildings rest on hard rock strata behave more like *Building A* during low intensity of ground shaking, wherein the lateral frictional resistance under the columns is more than by the horizontal shear induced in the building by lateral earthquake shaking. Once the inertia force exceeds the frictional resistance during strong ground shaking, these buildings behave more like *Building B*, wherein except the last column on the valley side, all other start sliding from the ground in the lateral direction.

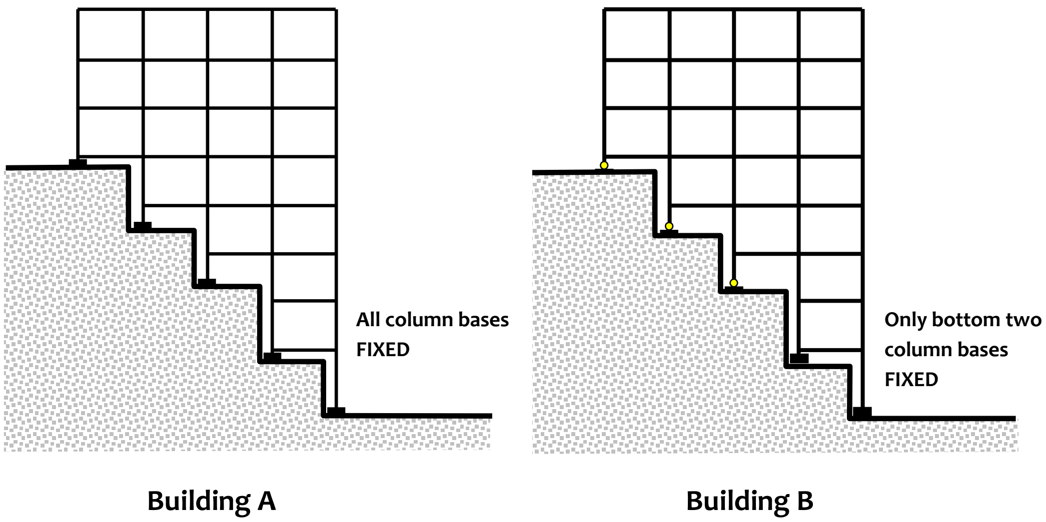


Figure 3.2 Building with different support conditions

Comparison of deformed shapes, and axial forces, shear forces and bending moments in members of these two possible buildings A and B under strong lateral force (Figure 3.3) suggests revealing information along VALLEY direction. Under small intensity of shaking, the lateral deformation is concentrated only in the portion of the building *ABOVE the uppermost support* (as in Building A), and cause predominantly large axial force in the valley-side columns below the ground level. This additional axial force, along with the existing gravity load, can cause compression failure of these columns, as observed during the 2011 Sikkim Earthquake (Figure 2.3). Under strong shaking, most column bases loose contact with the soil and cause large axial force, shear force and bending moment in columns, particularly in those *BELOW the uppermost support* (as in Building B), and is likely to cause catastrophic collapse of buildings under combined action of axial force, shear force and bending moment. Further, stability of such buildings is jeopardized by slope instability that can be triggered by ground shaking of strong intensity. The situation is slightly different in the outer frames along the ROAD direction. Amplification is seen only in axial force, but not in shear forces and bending moments (Figure 3.4).

Major dynamic characteristics of buildings on slopes include:

(a) Depending on the support condition, dynamic characteristics differ of buildings on slopes, and as a consequence, their responses also differ significantly.

(b) Number of columns founded on the slope depends upon the building configuration and the angle of hill slope. This controls the number of columns resting on flat ground along the foothill side and thereby affects the stability of buildings on these slopes.

(c) Stability of buildings on slopes is influenced by the number of storeys above the ground level.

(d) Fundamental translational modes of buildings on slopes are along the road and valley directions. As a consequence, the propensity of such buildings to topple over is higher especially along valley direction, wherein the columns are subjected to increased axial load during earthquake shaking.

Detailed analyses of RC frame buildings on hill slopes (Figure 3.5) indicate that

(a) Buildings that have short plan length (Building P) along ROAD direction perform better than those that of long length (Building Q); and

(b) Buildings that have short plan length (Building R) along VALLEY direction perform better than those that of long length (Building S).

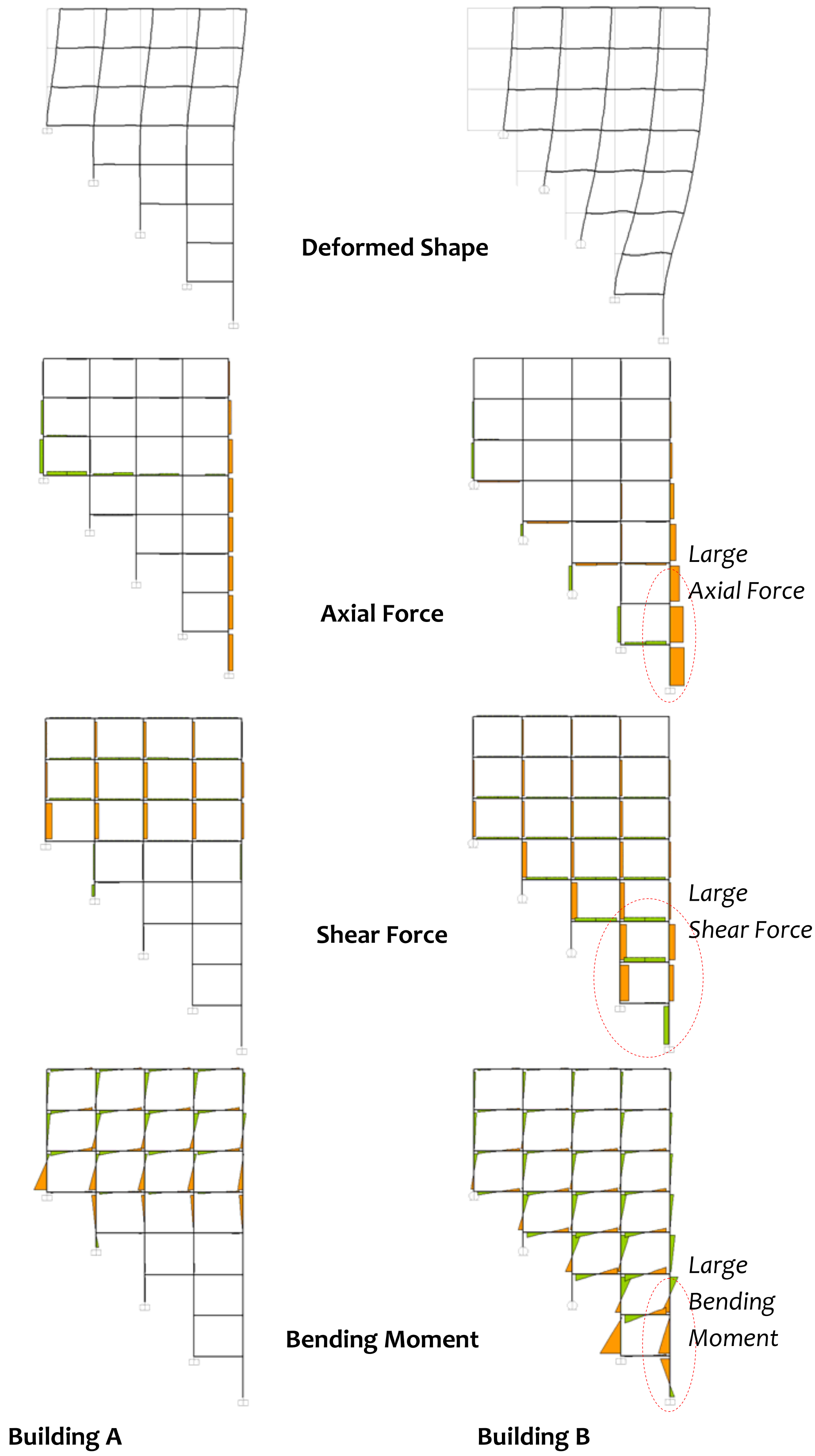


Figure 3.3 Deformed Shape, Axial Force, Shear Force and Bending Moment Diagram for Building A and Building B subjected to lateral load; the frames shown are along VALLEY direction

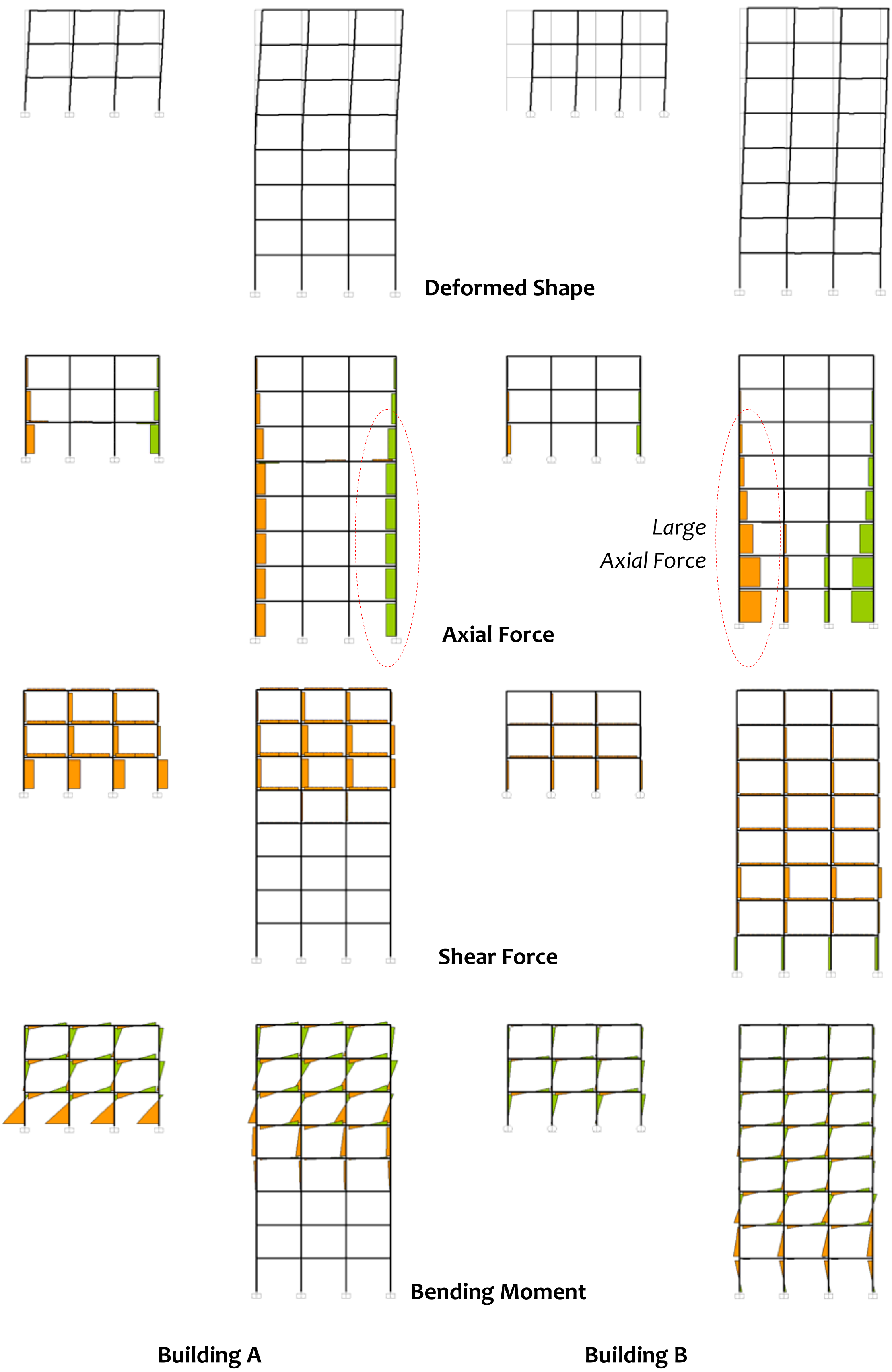


Figure 3.4 Deformed Shape, Axial Force, Shear Force and Bending Moment Diagram for Building A and Building B subjected to lateral load; the frames shown are along ROAD direction

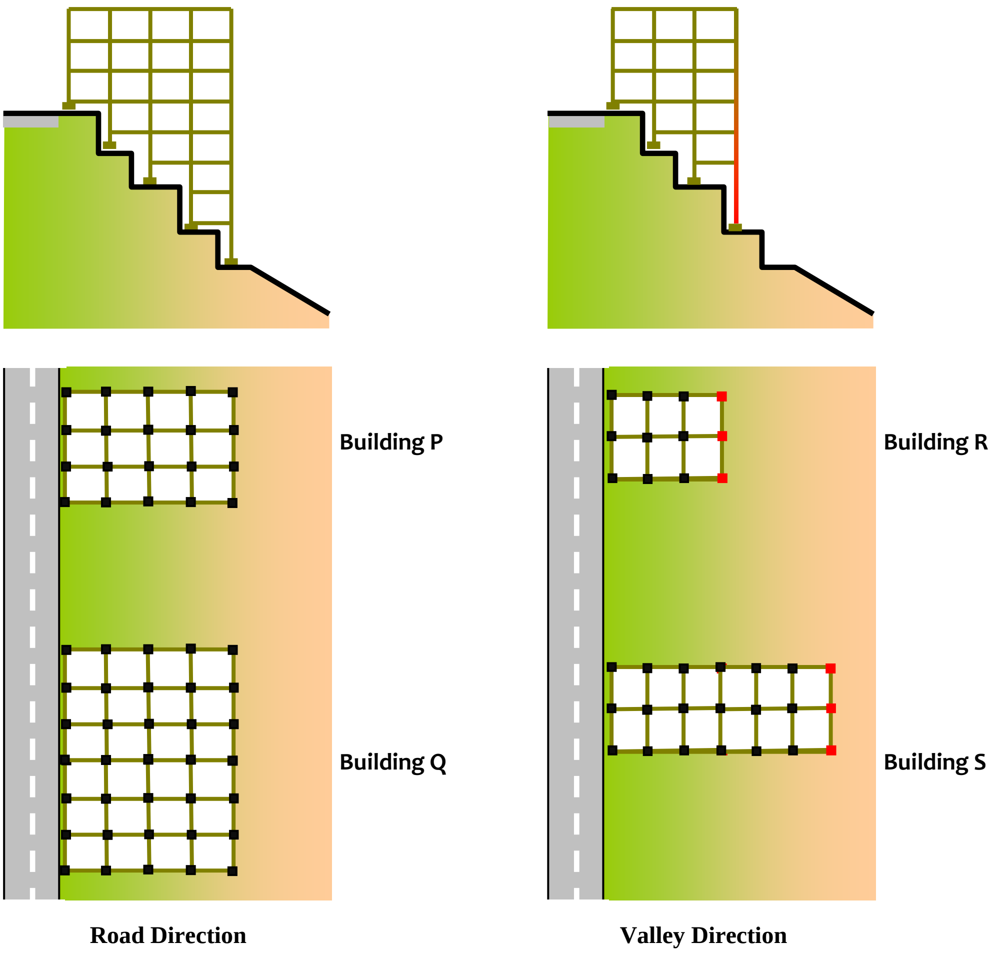


Figure 3.5 Deformed Shape, Axial Force, Shear Force and Bending Moment Diagram for Building A and Building B subjected to lateral load; the frames shown are along ROAD direction

3. CONCLUDING REMARKS

Field investigations and primary analyses of buildings on hill slopes suggests that buildings with good seismic performance in high seismic regions have two key characteristics, namely
(1) small plan (along both ROAD and VALLEY directions); and
(2) Only additional storeys above the uppermost ground support level.
But, currently, the quality of reinforced concrete work that is undertaken in the hill areas of Sikkim Himalayas is plagued by a number of challenges. These include: (i) poor quality of materials for concrete, (ii) hand mixed concrete, (iii) un-vibrated concrete, (iv) absence of seismic detailing of reinforcement grills and lack of connectivity between the vertical and horizontal members, and (v) improper preparation of base of the column pedestals. Thus, more attention is required to improve seismic safety of single unit dwellings on hill slopes of Sikkim Himalayas. More research is necessary to understand seismic behaviour and design of RC buildings with column footings at different levels along the hill slopes, especially along the steep and weak slopes of Sikkim Himalayas.

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