Concrete seismic configuration and detailing comparison between China and Sri Lanka

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Abstract. With the implementation of the “One Belt One Road” strategy, more and more Chinese companies are taking part in the engineering market in Sri Lanka. As BS codes are applied locally, concrete seismic configuration and detailing are different from Chinese ones. Therefore, the authors summarized the differences of planar and vertical irregularities, material properties and stirrups, column and beam between RDMSE and GB50011 to provide easy reference for engineers who are going to do projects in this country. It can be found that generally the planar and vertical irregularities are similar but the GB50011 have more detailed requirements; the steel strength and its elongation are similar in the two codes; column’s axial compression ratio limit in RDMSE are 44% lesser than the one in GB50011; and beam’s maximum reinforcement ratio in RDMSE is 20% lesser than the one in GB 50011.

1. Introduction
As China's "one belt, one road" strategy is advancing, more and more Chinese enterprises get involved in the construction market of Sri Lanka [1]. Because Sri Lanka concrete structure design adopts British standard BS8110, which does not consider earthquake effect. However, from 1819 to 1998, 18 earthquakes with magnitude between 5.0 and 6.0 were recorded around Sri Lanka. Therefore, the local structural engineering committee has prepared the manual of seismic structural measures "Reinforcement Detailing to Mitigate Seismic Effects" (hereinafter referred to as RDMSE) [2], which is different from the Chinese code, Code for seismic design of buildings GB50011-2010 (Edition2016) (hereinafter referred to as GB50011) [3]. This paper summarizes the practical experience of the finished projects in Sri Lanka, and compares the seismic structural configuration between GB50011 for the lowest seismic acceleration 0.05g and RDMSE, so that the Chinese structural engineers can better carry out the concrete structure design in Sri Lanka.

2. Building shapes and its structural elements layout

2.1. General
Similar to GB50011, RDMSE also requires that the layout of the building shape and its components should meet certain requirements, which are 1) it should be approximately symmetrical in plan for example, by having strong elements arranged symmetrically thus preventing the development of torsional effects; 2) it is desirable to have a uniform and continuous distribution of strength in the vertical direction; 3) It is desirable to have beams which form hinges before columns; 4) it is advisable to avoid inappropriate non-structural elements’ detailing; 5) it is advisable to set seismic gap for adjacent buildings, to prevent ponding during earthquakes [2].
2.2. Irregularities in plan
RDMSE specifies that for large re-entrant corners when A/L is more than 0.15 shown in Figure 1, it is considered to be geometrical irregularities in plan. Compared to RDMSE, A/L in GB50011 is more than 0.3 for irregular structures in plan. However, there is not requirements about the torsional irregularities and floor slab discontinuity specified in Section 3.4.3-1 in GB50011.

![Figure 1. Geometrically symmetric irregular structure](image)

Buildings with irregular plan shape should be separated using seismic joints which is specified in Section 4.1 of RDMSE. A seismic joint can separate building masses to form regular plan shapes so that they can behave independently. Similarly, the seismic joint is also proposed in Section 3.4.5 of GB50011 for irregular structures in plan.

It can be found that the regulations in the two codes for irregularities in plan are similar. However, the limits 0.15 for A/L in RDMSE is stricter than 0.3 in GB50011. And Chinese codes specify other two irregularities in plan, like torsional irregularities and floor slab discontinuity.

2.3. Vertical irregularities
It is advisable to limit the height to breadth ratio to less than 4 according to Dowrick [4]. However, the value in section 3.3.2 of JGJ3-2010 Technical Specification for Concrete Structures of Tall Building is from 3 to 8 according to different types of structures and seismic precautionary criterion [5].

For vertical irregularities, section 4.4 in RDMSE and section 3.4.3 in GB50011 are similar, including 1) vertical irregularities due to different adjacent story heights; 2) vertical irregularities due to mass distributions in adjacent stories; 3) vertical irregularities due to setback. However, there are not quantitative requirements in RDMSE for 1) and 2). The requirement for 3) in RDMSE is shown in the Figure 2.

![Figure 2. Vertical irregularities due to setbacks](image)

Compared with limit A/L=30% setback in RDMSE, the limit value in GB50011 is 25%, less than the RDMSE’s.

2.4. Effect of Relative strength of Beams and Columns
Similar to GB50011, the Section 4.5 in RDMSE also recommends the concept of Strong Columns and Weak Beams. As the reinforced concrete structures don’t consider about seismic load, it leads to when there is long span beams, structural engineers in Sri Lanka generally adopt deep beams and the strength of the column is less than the beam’s. Thus RDMSE specify that when long beams are unavoidable, it may be appropriate to use larger columns than required by static axial loads and
moments. However, RDMSE doesn’t include any regulations how to determine the sizes of columns with the consideration of seismic load which is clearly specified in GB50011.

2.5. Non-structural elements layout
Section 6.2.8 of RDMSE stipulates that 10mm thick flexible joint between the wall and its adjacent columns and top beams. Section 6.3.4 of GB50003-2011 Code for Design of Masonry Structures specifies that not less than 20mm gap between the wall and its adjacent columns and top beams, and add flexible materials in the gap [6].

2.6. Effect of Adjacent Building
Gaps between adjacent buildings in RDMSE are that 1) up to 6m height gap is not less than 30mm; 2) add 10mm for each 3m increment thereafter. Thus when the height is up to 15mm, the gap is not less than 60mm (30+10*9/3=60). The gaps in section 6.1.4.1 of GB50011 are that 1) up to 15m is not less than 100mm; 2) add 20mm for each 5m increment thereafter for seismic acceleration 0.05g which is similar to the one in Sri Lanka.

3. Material properties and Stirrups

3.1. Material properties
Concrete and reinforcement properties are shown in the Table 1.

| Items                              | RDMSE          | GB50011         |
|------------------------------------|----------------|-----------------|
| Concrete Strength                  | 20MPa~50MPa    | 20 Mpa~70Mpa    |
| Steel Strength                     | ≦460N/mm²      | ≦400N/mm² for   |
|                                    |                | longitudinal reinforcement; |
|                                    |                | ≦335N/mm² for stirrups |
| Steel elongation                   | ≧10%           | ≧9%             |
| Yield strength from tests/         | ≦1.3           | ≦1.3            |
| characteristic yield strength      |                |                 |
| Tensile strength from tests/       | ≧1.25          | ≧1.25           |
| characteristic yield strength      |                |                 |

According to Table 1, it can be found that 1) more concrete strength grades can be used in GB50011; 2) both codes control the steel strength; 3) mechanical and elongation properties almost the same for the steel reinforcement.

3.2. Stirrups and cross-ties
Stirrups and cross ties in the two codes refer to the Table 2. And dl means the diameter of longitudinal bars.

| Items                              | RDMSE                                      | GB50011                                      |
|------------------------------------|--------------------------------------------|----------------------------------------------|
| Stirrup hooks                      | Stirrups shall always have 135° hooks at both ends | Stirrups shall always have 135° hooks at both ends |
| Cross-ties                         | Cross-ties may have 90°hook and a 135°hook at the other end. | Cross-ties may have 90°hook and a 135°hook at the other end for easy fixing |
| Length of hook measured from tangent point | ≧10dl and 100mm for plain bars; ≧6dl and 80mm for ribbed bars | ≧10dl and 75mm |
According to Table 2, it can be found that 1) stirrup hooks and cross-ties are the same for both codes; 2) the length of hook measured from tangent point in RDMSE is stricter.

4. Column

4.1. Column Dimensions

Requirements of column sizes in the two codes refer to Table 3. And bmin means the shorter dimension of column.

| Items                              | RDMSE                  | GB50011               |
|------------------------------------|------------------------|-----------------------|
| Shorter dimension of column        | b\(_{\text{min}}\) \(\geq\) 250mm | b\(_{\text{min}}\) \(\geq\) 300mm |
| diameter of circular columns       | diameter \(\geq\) 300mm | diameter \(\geq\) 350mm |
| Cross sectional area of column     | \(\geq 75000\text{mm}^2\) | -                     |
| Longer side/ shorter side of column| \(\leq 4\)             | \(\leq 3\)            |
| axial compression ratio            | 0.5                    | 0.9                   |

According to the Table 3, it can be found that 1) minimum sizes of column in RDMSE is smaller, when Chinese engineers follow GB50011 to do the design, it would be uneconomical in the local market and it happened in some finished projects which I engaged in; 2) Axial compression ratio in RDMSE is much stricter.

4.2. Column Reinforcement

Column reinforcement requirements in RDMSE and GB50011 refer to Table 4. Ln means the clear height of a column; bmax means the maximum side of the column.

| Items                              | RDMSE                  | GB50011               |
|------------------------------------|------------------------|-----------------------|
| Reinforcement ratio                | 1%~4%                  | 0.5%~5%               |
| Minimum diameter of longitudinal bars | 16 mm                  | 12 mm                 |
| Confinement zone length            | \(\text{Max(} \geq 500\text{mm, } \frac{L_0}{6}, \frac{b_{\text{max}}}{b_{\text{max}}})\) | \(\text{Max(} \geq 500\text{mm, } \frac{L_0}{6}, \frac{b_{\text{max}}}{b_{\text{max}}})\) |
| Stirrup space at the confinement zone | \(\geq 100\text{mm, and}\) | \(\leq 8d_l\) and 100mm |
| Stirrup space at the non-confinement zone | \(\geq 200\text{mm and } 1/2b_{\text{min}}\) | 15d_l |

According to Table 4, it can be found that 1) minimum reinforcement ratio and diameter of longitudinal bars in RDMSE are larger than the ones in GB 50011; 2) confinement zone length in the two codes is the same; 3) stirrup space at the confinement zone and the non-confinement zone in the two codes are similar, and typically stirrup spacing 100mm and 200mm are adopted respectively for the confinement zone and the non-confinement zone in actual projects in Sri Lanka.

In order to further illustrate and summarize the desirable arrangement of stirrups for columns as per RDMSE which is important during column’s detailing, following Figure 3 is shown.
5. Beam

5.1. Beam Dimensions
According to the local practice, secondary beams are seldom adopted and thick slabs are preferred. Thus, main frame beams are compared in the two codes. Beam dimension requirements in the two codes refer to Table 5.

| Items             | RDMSE                                      | GB50011                                      |
|-------------------|--------------------------------------------|----------------------------------------------|
| Beam width        | -greater than 250mm                        | -not less than 200mm;                        |
|                   | -less than or equal to beam depth+         |                                              |
|                   | width of column in perpendicular direction|                                              |
|                   | to beam axis                              |                                              |
|                   | -greater than larger of 3*slab thickness   |                                              |
|                   | and 300mm                                 |                                              |
|                   | -less than 1/4 of clear span              |                                              |
| Beam height       | -greater than larger of 3.5* the beam     |                                              |
|                   | width                                    |                                              |
|                   | -not more than 4* the beam width;         |                                              |
|                   | -not more than 1/4 of clear span          |                                              |

According to the Table 5, it can be found that both codes have the limit requirements for the sizes of beam, however, the requirements in RDMSE are slightly stricter than Chinese ones.

5.2. Beam Reinforcement
Beam reinforcement requirements in RDMSE and GB50011 refer to Table 6. hb means the height of a beam; and ds means the diameter of the stirrup bar.

| Items                             | RDMSE                        | GB50011                                    |
|-----------------------------------|------------------------------|--------------------------------------------|
| Maximum reinforcement ratio       | $\leq 2\%$                  | $\leq 2.5\%$                              |
| Minimum diameter of longitudinal bars | 12mm                        | 12mm                                      |
| Confinement zone length           | $2h_b$                      | 1.5$h_b$ and 500mm                        |
| Stirrup space at the confinement zone | min($h_b/4$, 150mm, 8$d_s$) | min($h_b/4$, 150mm 8$d_s$)               |
| Stirrup space at the non-confinement zone | $h_b/2$, 300mm, and 12$d_s$ | refer to Section 9.2.9 of GB50010-2010 (Edition 2015) |
According to Table 6, it can be found that 1) maximum reinforcement ratio in RDMSE is lesser than the one in GB50011; 2) minimum diameter of longitudinal bars in the two codes are the same; 3) stirrup space at the confinement zone in the two codes is similar; 4) compared to RDMSE, there are more detailed requirement in GB50010-2010(Edition 2015) [7].

In order to further illustrate and summarize the arrangement of links for a beam as per RDMSE which is critical during beam’s detailing, following Figure 4 is shown. Sk means the stirrup space at the confinement zone.

### Figure 4. Arrangement of links in a beam

#### 6. Conclusions

According to concrete seismic configuration and detailing comparison between China and Sri Lanka, it can be concluded in the following:

1. For irregularities in plan, generally RDMSE and GB 50011 are similar. However, the limits 0.15 for A/L in RDMSE is stricter than 0.3 in GB50011. And Chinese codes specify other two irregularities in plan, like torsional irregularities and floor slab discontinuity.
2. For vertical irregularities, there are not quantitative requirements for vertical irregularities due to different adjacent story heights and vertical irregularities due to mass distributions in adjacent stories. And the limit value for vertical irregularities due to setback in GB50011 is stricter.
3. Both GB50011 and RDMSE have the Strong Columns and Weak Beams concept.
4. Both GB50003-2011 and RDMSE require gap between walls and its adjacent columns and top beams; and for half story height masonry, both GB50011 and RDMSE stipulate to avoid bracing effect.
5. Seismic gap width requirement in GB50011 is stricter than the one in RDMSE.
6. Both GB50011 and RDMSE control the steel strength and elongation and they have similar limit values.
7. Hooks for stirrups and cross-ties are similar in both codes, however, the length of hook measured from tangent point in RDMSE is stricter.
8. Minimum sizes of column in RDMSE is smaller, however, axial compression ratio in RDMSE is much stricter.
9. The limit requirements for the sizes of beam in RDMSE are slightly stricter than Chinese ones.
10. Column’s minimum reinforcement ratio and diameter of longitudinal bars in RDMSE are larger than the ones in GB 50011;
11. Column’s confinement zone length in the RDMSE and GB50011 is the same; and its stirrup space at the confinement zone and the non-confinement zone in the two codes are similar;
12. Beam’s maximum reinforcement ratio in RDMSE is lesser than the one in GB50011; and its minimum diameter of longitudinal bars in the two codes is the same.
13. Beam’s stirrup space at the confinement zone in the two codes is similar.

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