Project Title:	Labour and Cost Efficient Construction Method for Retrofitting RC Columns with FRP
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Objective

- To quantify the plastic hinge zone in a column/wall over which jacketing is required for retrofitting existing RC buildings subjected to earthquakes;
- To quantify the equivalent plastic hinge length, with which the ductility and deformation capacity of an RC column/wall is calculated for the seismic assessment of structures; and
- To provide construction guidelines for minimum retrofitting work of an RC column/ wall with cost estimation.

Background

As noted by seismic experts, soft storey failure of columns is a major problem in Hong Kong. Therefore, retrofitting of existing RC columns and walls would be a major task for earthquake retrofitting. External jacketing with fibre reinforced polymer (FRP) is currently the most effective, simplest and least expensive technology for RC column retrofitting. In fact, FRP jacketing is particularly effective in mitigating seismic damage to soft storey structures by significantly increasing the ductility of the RC columns, therefore avoiding the strength degradation of structural members under very large earthquake displacement. Investigators have developed analytical and numerical methods to study the plastic hinge zone, overcoming the limitations of experimental testing for the problem. Key factors and mechanisms that affect the plastic hinge length have been studied through experimental methods, analytical methods and the finite element method (FEM). These findings have provided a better understanding of the problem and the reason for the contradicting findings reported in the literature. This research work aims at transferring the theoretical work into practical engineering applications by developing construction methodology and guidelines for retrofitting RC columns with minimum labour and construction costs.

Methodology

The RC columns with/without FRP wrapping were tested under both an axial and lateral load. Digital Image Correlation (DIC) Measurement Systems and traditional instrumentation were used to measure the strain and deformation field on the concrete or FRP surfaces so that the detailed strain field in the plastic hinge region was recorded continuously during testing. A large number of strain gauges were installed inside the steel reinforcing bars to obtain the strain distribution of the steel reinforcing bars and to measure the rebar yielding zone without disturbing its bond with concrete.

Results and Findings

The minimum retrofitting work can be designed in accordance with the following procedure:

1. Based on the design requirements, such as loading and seismic demand, calculate the internal forces (including axial force, bending moment and shear force) of a particular RC column, based on Hong Kong concrete code (“Code of Practice for Structural Use of Concrete”) are calculated.

2. Using the calculated internal forces and/or ductility demand, the FRP jacket thickness based on existing guidelines, such as ACI 440.2 (2008) or the Hong Kong Guide is determined. Chapter 12 in ACI 440.2, which provides design guidelines for RC column jacketing, is used design examples are available in Section 15.8 and 15.9 in ACI 440.2 (2008). The design calculation will give the thickness and number of FRP layers.

3. The minimum jacket length (from bottom of column), L_{min}, can then be calculated using the following equation.

$$L_{\min} = 1.25\left[1.07e^{-0.6\lambda_f} n^{0.16}\left(\frac{2r}{b}+0.2\right)^{0.1}+0.6\right]d$$

where n is the axial load ratio; r, b and d are the corner radius, width and depth of the column cross-section, respectively; and λ_f is the FRP confinement ratio, which is given by

$$\lambda_f = \frac{2 f_{frp} t}{b f_{co}}$$

where f_{co} is the strength of concrete; and t and f_{frp} are the total thickness and strength of the FRP jacket, respectively.

Recommendations

1. For square and rectangular columns, grinding is compulsory at every corner. The corner radius (r) should be no more 20 mm.
2. The primary fibre direction of the FRP should be parallel to the transverse direction of the column.
3. The length of the overlap of each layer of the jacketed FRP should be more than 150 mm.
4. The FRP jackets should be applied at the largest moment regions. If the column top is not a cantilever end, FRP jackets may need to be applied at both ends of the column depending on the calculations.