Secondary Cracking for a Ductile Performance in Reinforced Concrete Walls

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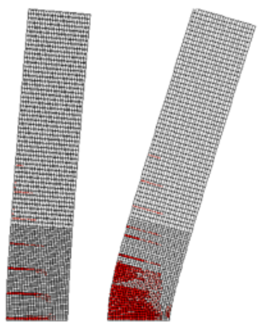
POOR PERFORMANCE HAS BEEN EXHIBITED BY LIGHTLY REINFORCED CONCRETE WALLS IN PAST EARTHQUAKE EVENTS, INCLUDING SINGLE-CRACK FAILURES FROM A LARGE CONCENTRATION OF PLASTICITY OCCURRING OVER A SHORT HEIGHT AT THE WALL BASE. THIS RESEARCH INVESTIGATES THE PLASTIC HINGE LENGTH AVAILABLE IN LIGHTLY REINFORCED RECTANGULAR WALLS WHICH ARE REPRESENTATIVE OF WALLS USED IN REGIONS OF LOW-TO-MODERATE SEISMICITY.

INTRODUCTION

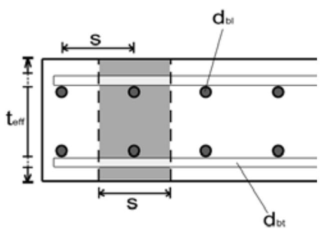
Reinforced concrete (RC) walls and cores are widely used throughout the building stock in areas of low-to-moderate seismic regions such as Australia. Such elements are used as the primary structure in resisting lateral loads, including seismic ground motions. Some lightly RC walls were observed to perform poorly in the February 22nd Christchurch earthquake, with several cases of a single crack forming at the base in the plastic hinge region in contrast to the expected distributed cracks leading to fracture of the longitudinal reinforcement. This is of major concern for places of low-to-moderate seismicity, such as Australia, where the great majority of the buildings incorporated RC walls with low longitudinal reinforcement ratios.



In light of these recent observations, there is a need to investigate the amount of longitudinal reinforcement required to initiate secondary cracking and allow a distribution of plasticity. These results are essential knowledge for vulnerability studies of reinforced concrete buildings that are being carried out by the authors within the earthquake mitigation component of the Australian Bushfire and Natural Hazards Cooperative Research Centre.

SECONDARY CRACKING MODEL – SIMPLE APPROACH

The lack of distributed plasticity (inelastic deformation) is driven by the low tensile force produced by the small number of longitudinal reinforcing steel bars that cross a primary crack. Consequently, the maximum stress that can be developed in the concrete above the first crack (σ_{crack}) may be insufficient to exceed the flexural tensile strength of the concrete ($f_{ct.fl}$) and hence secondary cracks are unable to form. Thus, equations can be derived to estimate whether secondary cracking will occur above the "primary crack". The figure below shows the shaded effective area (A_{eff}).



The following equations can determine if the reinforcement ratio in the wall is sufficient to cause secondary cracking:

$$\sigma_{crack} = \frac{T}{A_{eff}} = \frac{n_l A_b f_u}{t_{eff} s} \geq f_{ct.fl}$$

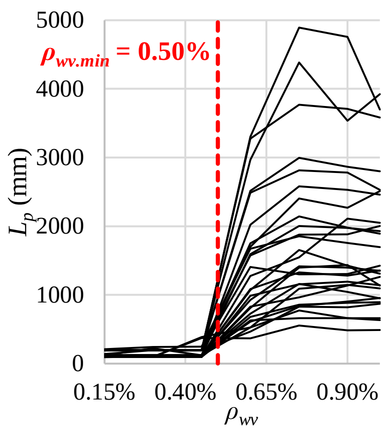
Thus, the equation can be rearranged to give the minimum longitudinal reinforcement ratio required in a wall to allow secondary cracking:

$$\rho_{wv.min} = \frac{(t - n_t d_{bt}) f_{ct.fl}}{f_u t}$$

The equation above estimates a much higher ρ_{wv} (for a given concrete strength and N-type reinforcement) in comparison to the 0.0015 minimum currently stipulated in AS3600:2009 (Standards Australia, 2009)

FINITE ELEMENT RESULTS

VecTor2, a state-of-the-art finite element program was employed to run numerical analyses on walls representative of those found in regions of low-to-moderate seismic regions. The purpose of this study was to observe the onset of secondary cracking for a range of parameters and ultimately calculate the plastic hinge length. The figure below gives the plastic hinge length results for a range of walls (f_{cmi} of 40MPa and using N-type steel) dependent on the longitudinal reinforcement ratio (ρ_{wv}).



CONCLUSION

The VecTor2 results show that the 'Secondary Cracking Model' gives a good prediction of the onset of secondary cracking and consequently of distributed plasticity. A plastic hinge length equation for these types of walls is derived from the finite element modelling results. This will ultimately help in improving the predictions for the displacement capacity of RC buildings in low-to-moderate seismic regions, such as Australia.

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