1. Introduction

The plastic hinge length is used in reinforced concrete (RC) seismic detailing to determine the region where additional confinement requirements apply, but also in performance-based seismic design and assessment in order to quantify the deformation capacity of RC columns. It has been studied, quantified and calibrated against tests on isolated column specimens. In the typical test, a cantilever column fixed at the base and carrying a constant axial load is driven to a reversed cyclic lateral drift history. In columns that do not fail by web crushing, pullout rotation increases gradually with imposed drift, claiming a predominant share of the members’ deformation capacity near the ultimate limit state. Column deformation capacity at yielding and ultimate may be computed using a variety of models [1–7]. A stick model is a common point of reference to this purpose: The length of the cantilever $L_s$ corresponds to the shear span of an actual frame member under lateral sway (Fig. 1a); the aspect ratio of the member $L_s/h$, where $h$ is the cross section depth, quantifies the intensity of shear force demand in the member. Inelastic activity is assumed to occur within an equivalent “plastic hinge length”, $L_{pl}$, whereas the segment of the member outside $L_{pl}$ is assumed to behave elastically. Displacements are calculated from flexural curvatures assuming the curvature distributions of Fig. 1(b,c), which correspond to development of yielding $\phi_y$ and post-yielding $\phi_{pl}$ flexural strengths at the support. The plastic rotation developing in the hinge due to flexure is $\theta_{pl} = (\phi_y - \phi_{pl}) \cdot L_{pl}$, similarly, the plastic rotation owing to bar pullout from the support is $\theta_{pl}^{slip} = \phi_{slip}^{y} - \phi_{slip}^{pl}$. The

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corresponding terms are (Fig. 1e) \((x)\) is the length counting from the support to the tip of the cantilever column under study):

\[
\theta_s = \theta_{sL} = \theta_{s,\text{anch}} - \theta_s^{\text{slip}} = \theta_s^{\text{slip}} = \theta_{s,\text{slip}},
\]

\[
\theta_s^{\text{slip}} = -\theta_{s,\text{slip}} = \theta_{s,\text{slip}} = \theta_{s,\text{slip}}.
\]

where \(c_s\) is the depth of compression zone at the critical cross section (here it is assumed to remain constant after yielding) and \(L_b\) the total available anchorage length, whereas \(L_b,\text{min}\) is the minimum required anchorage length to yield a typical bar (diameter: \(D_b\)), at a yield stress \(f_y\), considering a uniform bond strength equal to the bond strength of \(f_{b,max}\).

Rotation of the critical cross section occurs about the centroid of the compression zone (located at a distance 0.4 \(c_s\) from the extreme compressed fiber based on the equivalent uniform stress block [8]). Parameters \(s_y\) and \(s_u\) are values of reinforcement pullout slip from the support anchorage at yielding and ultimate (Fig. 1e). Term \(\epsilon_{a,u}\) represents the maximum sustainable penetration of yielding into the anchorage (Fig. 1e); the maximum reinforcement strain, \(\epsilon_{u}\), that can be supported by the reinforcement at critical cross section (i.e. support) may be estimated assuming that at the extreme, when the anchorage attains its ultimate development capacity the strain distribution along the anchored length is bilinear: \(\epsilon_y = \epsilon_u + 4(L_b - L_b,\text{min})f_{y}^{res}(D_b E_{sh})\), where \(E_{sh}\) is the hardening modulus of steel and \(f_{y}^{res}\) is the residual bond strength due to cover splitting/delamination. The corresponding maximum and yield flexural curvatures are defined as: \(\phi_y = \epsilon_y \) and \(\phi_{u} = \epsilon_{u}\) / \((d - c_s)\), whereas the total plastic rotation capacity, \(\theta_{pl}\), that may be sustained by the member may be estimated through reverse engineering as [9]:

\[
\theta_{pl}^{\text{slip}} \approx 0.5\left(\phi_x - \phi_y\right) - \phi_a, \phi_{pl}^{(i)} = \left(\phi_x - \phi_y\right), \phi_{pl}^{(ii)} = \left(\phi_x - \phi_y\right) - \left(1 - M_a/M_a\right)L_a \Rightarrow \phi_{pl}^{(ii)}
\]

\[
= \left(\phi_x - \phi_y\right)\left(0.5\epsilon_{s,u} + \alpha L_a\right)
\]

where in Eq. (2a) index (i) denotes pullout from support and (ii) flexure in the shear span; term \(\alpha\) is the strain-hardening ratio of the reinforcement, \(\alpha = 1 - M_a/M_a\), defined from cross section analysis at ultimate moment given a simplified stress–strain law for the hardening branch of steel. Introducing the concept of the plastic hinge length, \(L_{pl}\), the plastic rotation capacity from Eq. (2a) is written as:

\[
\phi_{pl}^{(ii)} = \left(\phi_x - \phi_y\right)\left(0.5\epsilon_{s,u} + \alpha L_a\right)
\]

Empirical equations for the plastic hinge which have prevailed in
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