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Effects of podium interference on shear force distributions in tower walls supporting tall buildings

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ABSTRACT

High rise constructions featuring a podium surrounding tower walls are often favoured for the versatile functionality of the building. It is shown in this paper that the podium can impose significant differential restraint on coupled tower walls. Incompatible tower wall displacements under lateral loads were found to be the main contributor to the generation of in-plane strutting forces in floors above and below the podium-tower interface level. Shear force localisations in the interior tower wall immediately above the interface was found to be the direct consequence of these actions. Key parameters contributing to this detrimental shear force localisation in a tower wall were analysed by way of parameter studies on representative models of the building and sub-assemblages. It is revealed that the in-plane rigid diaphragm assumption commonly adopted in practice can significantly suppress compatibility forces generated within the building floor leading to unconservative design of the tower walls. Elaborate nonlinear model has been examined to showcase the consequences of understating the shear demands on these walls.

1. Introduction

Podiums are augmented floor area at the lower level of a high rise building which are common in metropolitan areas in regions of low-to-moderate seismicity. The lateral load resisting system for such building configurations comprises moment resisting frames and shear (or core) walls. As the tower walls of the building is offset from the centre of the podium, high torsional moments can be imposed on the podium [1,2]. High shear forces can also be induced on the structural walls thereby jeopardising their structural integrity when subject to severe earthquake ground shaking. Recommendations against this form of construction have not been mandated in many design codes of practices in spite of potential undesirable behaviour in a rare seismic event [3,4].

At the podium-tower interface, horizontal forces are transferred from the tower to the podium. Reactive forces are developed at the podium-tower interface to resist the overturning actions (Fig. 1). The reacting mechanism is synonymous to the back span of a cantilever. Intuitively, the described backstay mechanism can induce high intensity shear force in the structural (tower) wall within the podium. The amplitude of the induced shear force is dependent on the in-plane flexibility of the floor structure connecting the pair of walls. This was first investigated in the early works of Bevan-Pitchard et al. [5] by means of linear analysis of the tower walls. A quarter of a century later, Rad and Adebar [6] extended their work into the inelastic domain and concluded that stiff sub-grade diaphragms and perimeter walls can lead to shear-critical conditions occurring in tower walls below their base.

The backstay phenomenon as described is well known [7]. However, shear anomalies generated by differential restraints on a tower wall (which has an offset from the centre of the podium) is not well understood. The structural wall which is closer to the centre of the podium (referred herein as the *interior* wall) is subject to higher moment restraints from the podium structure than the *exterior* wall. As a result, high strutting forces are developed in the connecting floor structure (beam and slab) to maintain compatibility. This strutting action can only be modelled accurately if the horizontal in-plane deformation of the floor diaphragm has been incorporated into the modelling. Thus, the extent of such actions can be misrepresented by analyses in which the (usual) rigid floor diaphragm assumption has been made. Effects of diaphragm flexibility on the lateral response behaviour of the wall were examined by Pantazopoulou and Imran [8] Shin et al. [9] and Su et al. [10]. It was found that diaphragm flexibility in buildings (featuring vertical or on-plan irregularity) can adversely affect

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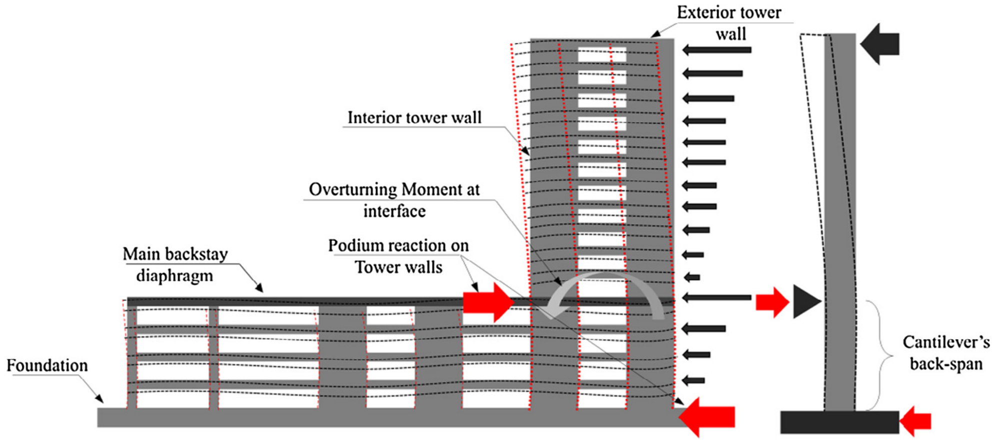
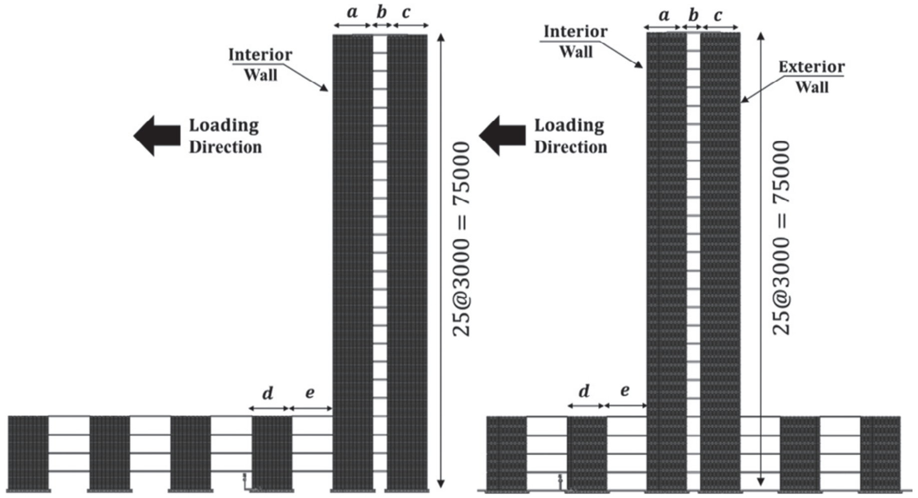


Fig. 1. Backstay action in a podium-tower sub-assemblage.



(a) Tower walls offset from the centre **(b) Centrally positioned tower walls.**

Fig. 2. Example podium-tower sub-assemblages.

dual wall-frame interaction. This issue has been highlighted in the PEER/ATC 72-1 document [7] inciting practitioners to use explicit floor models at the podium-tower interface, and particularly so in situations where there are high transfer forces.

Rutenberg and Bayer et al. [11,12] studied the prevalence of incompatibility (strutting) forces in slabs and beams connecting structural walls of different base dimensions. They concluded that these in-plane forces were the result of incompatible inelastic deformations within the structural wall. Gardiner et al. [13] and Bull [14] further examined incompatibility issues resulted from abrupt stiffness variations up the height of the building and dual frame-wall interaction. Their work highlighted the detrimental increase in the transfer (in-plane) forces when the structure undergoes inelastic response behaviour. Diaphragm-wall interaction issues is further highlighted in the New Zealand earthquake loading standard, NZS 1170.5 [15] in which more detailed analytical models and procedures are mandated to encapsulate the effects of diaphragms interference on the seismic behaviour of the structure.

The implications of podium-tower interactions as described have not been thoroughly covered in the research literature or in code provisions.

Table 1
Geometric configuration of the examined sub-assemblages.

Dimension, **indication**	Units in [mm]
Length of coupling beam, **a**	2000
Tower walls length, **a** & **c**	6000
Tower wall thickness	300
Podium wall length, **d** (typical)	6000
Coupling beam depth	1000
Clear podium span, **e** (typical)	6000
Effective slab width (podium) [16]	3100
Podium wall thickness (Typical)	600

Table 2
Material properties used (structural walls).

Material properties	
f'_C	40 MPa
Poission's ratio	0.2
E_c	31.6 GPa