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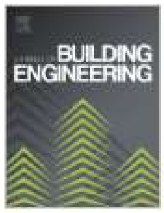

Earthquake-resistant buildings with steel or composite columns: Comparative assessment using structural optimization

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Highlights

- Assessment of buildings with different types of structural elements in an objective way using structural optimization.

- Seismic demand vs. cost curves defined are indicative of the relationship between cost and capacity requirements.
- Roughly linear demand vs. cost for buildings with composite columns and roughly bilinear for buildings with steel columns.
- Fundamental period bounds employed can limit significantly the range of feasible designs.
- The composite design approach seems to adapt better than pure steel design to increasing seismic demands.

Abstract

This work investigates and compares the cost-effectiveness of seismically designed buildings having either pure steel or steel-concrete composite columns. In order to ensure an objective comparison of these two design approaches, the assessed building designs are obtained by a structural optimization procedure. Thus, any bias that would result from a particular designer's capabilities, experience, and subjectivity is avoided. Hence, a discrete Evolution Strategies optimization algorithm is employed to minimize the total cost of materials (steel and concrete) used in a structure subject to constraints associated with: (a) Eurocode 4 provisions for safety of composite column-members, (b) Eurocode 3 provisions for safety of structural steel members, and (c) seismic system behaviour and resistance. Extensive assessments and comparisons are performed for a variety of seismic intensities, for a number of building heights and plan configurations, etc. Results obtained by conducting 154 structural design optimization runs provide insight into potential advantages attained by partially substituting steel (as a main structural material) with concrete when designing the columns of earthquake-resistant buildings.

Introduction

The incorporation of steel-concrete composite elements in a structure is nowadays regarded as established design and construction practice. Nevertheless, the investigations conducted on the conditions under which such practice is more cost-effective than other alternatives are rather limited. The use of composite elements is typically seen as an alternative to the use of pure steel elements. The use of each of these two types of elements is associated with certain advantages and disadvantages. Therefore, it is essential to comparatively assess structures incorporating either type of elements.

The purpose of this work is to assess multi-storey composite buildings with steel-concrete composite columns with respect to their cost effectiveness and seismic resistance capability. The assessments performed include comparisons with pure steel buildings. To ensure that all assessments and comparisons are made in an objective manner, the structures considered are designed in a way that optimal usage of the available materials and cross-sectional geometries is achieved. Thus, the designs attained do not depend on a designer's capabilities, experience and subjectivity, but are the outcome of an objective automatic design optimization procedure.

The seismic design optimization framework utilized in the present work is described in detail in Ref. [20].

Extensive assessments and comparisons are made herein for composite and pure steel buildings. Optimal structural designs are identified for a variety of seismic intensities, for a number of building heights and plan configurations, etc. The optimization results allow for an objective comparison of various designs in terms of required materials cost and achieved capacity to withstand earthquake actions and provide insight into the relative cost-effectiveness of the composite and pure steel design approaches.

Section snippets

Structural design optimization

Standardized steel sections are used for all structural elements (composite or pure steel) in this work. Hence the search space consists only of discrete design options, which renders the investigation performed a discrete optimization problem. The procedure developed in Ref. [20] is adjusted and applied herein. In particular, an Evolution Strategies algorithm is employed, which is a population-based evolutionary optimization method. At each ES-generation, this algorithm uses recombination and…

Adjustment of seismic demands

The seismic structural performance is determined by displacement-controlled nonlinear pushover analyses up to a targeted top displacement Δ_{target} according to the provisions of ASCE/SEI 41–06 [24] and FEMA 440 [25]. The magnitude of the required displacement depends on various problem-related variables: type of soil, seismic hazard of the area, expected load distribution, etc. This requirement is increased for structures of high economical value or importance to the public safety. The same...

Fundamental period formulas

ASCE/SEI 41–06 [24] and Eurocode 8 [27] provide approximate formulas to calculate the fundamental period of steel moment resisting frames using only their total height. In particular, ASCE/SEI 41-06 suggests its calculation through:$T = 0.035 \cdot H^{0.8}$,where *H* is the building height in feet, while Eurocode 8 defines it as:$T = 0.085 \cdot H^{3/4}$.The alternative formula for buildings up to 12 storeys and storey height at least 10ft is: $T = 0.1 \cdot n$,where *n* is the number of storeys of the building.

Goel and Chopra [28]...

Reference building (6 storeys, 5 × 5 bays)

The building selected as a reference for the numerical investigation of the present work is a 6-storey space frame of square floor plan with 5 bays in each horizontal direction (Fig. 2(a)). Bracings are (optionally) installed at the middle bay of each of the 4 external sides of the building. The bay width along both *x*- and *y*-directions is 5.5 m, while the height of each storey is 3.5 m, resulting in a total building height of 21 m. This is assumed to be a residential building, which implies a...

Structural optimization is a powerful computational tool which assists engineers in efficiently searching for cost-effective designs within extensive solution spaces. The existing literature includes several design optimization applications for pure steel structures (e.g. Refs. [[1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11], [12]]). Design optimization applications for structures with steel-concrete composite columns have appeared primarily in recent years ([[13], [14], [15], [16], [17], [18], [19], [20]]). The comparisons between pure steel and composite buildings presented in the above publications cover a narrow spectrum of design cases. Thus, although some information and optimization results are provided in the relevant available literature, additional assessments are needed for a more comprehensive comparison between the alternatives of pure steel and composite columns in optimally designed multi-storey buildings.

In the present paper, structural optimization is applied for the seismic design of composite buildings, in which the steel-concrete columns consist of steel members with standard I-shaped sections (HEB) fully encased in concrete. Moreover, buildings with pure steel columns are optimally designed using standard HEB sections. Steel beams with standard I-shaped sections (IPE) and (optional) steel bracings with standard L-shaped sections are considered for all design cases (using either composite or pure steel columns). All buildings assessed are required to satisfy the provisions of Eurocode 4 for the steel-concrete composite members and Eurocode 3 for the pure steel members. Seismic actions are taken into account through lateral deflection constraints evaluated using nonlinear static pushover analyses. Moreover, the fundamental periods of the optimally designed buildings are determined and assessed. All structural analyses required during any optimization run are performed with the software OpenSEES [21], which is automatically invoked by a discrete Evolution Strategies optimization algorithm.

Concluding remarks

In this work, a total number of 154 structural optimization runs were performed to comparatively assess buildings with pure steel and steel-concrete composite columns with respect to their total material cost for a variety of horizontal displacement capacity demands. The optimization procedure employed enabled a fair comparison between these two design approaches, as the assessment of optimized designs ensures that each approach has been applied as effectively as possible to meet structural…

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