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Design example for a reusable seismic frame design

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Abstract: *Circular design involves the use of innovative construction techniques that can be easily disassembled, reused, or recycled at the end of their useful life. This paper focuses on the development of the reusable design case-study concept for the seismic frame design as typically used in New Zealand's stee-frame structures. The paper proposed a reusable optimized design for the entire seismic frame. When optimizing welded structural dimensions, whether in terms of weight or cost, the result is a reduction in the weight of the steel used. This weight reduction directly correlates to a reduction in environmental impact since the environmental impact is directly related to the mass of the structure. The environmental impact of welding technology also depends on the size of the weld, which indirectly affects the mass of the structure. Since the dependence on mass is present in all three areas, but in different ways, a multi-objective function optimization approach was used in this paper to consider these three areas together while partly considering them independently.*

Keywords: *Welded Frame Design, Structural Optimization, Environmental Effects, Cost Calculations*

1. INTRODUCTION

While Industry 4.0 is gaining traction in manufacturing, it has yet to be substantially explored in the building industry. This research will result in the deployment of Industry 4.0 throughout the construction value chain, which will be a completely new capability. It will offer new ways of thinking, technologies, processes, and business models to ensure that the industry transitions to Construction 4.0 and achieves a quantum leap in technology adoption, decision support, and data utilization. While quantifying the economic impact of this shift is difficult, we do have the following data. This research project employs Industry 4.0 concepts to help the construction industry transition to a more technologically advanced sector. Currently, the primary goal is to provide a methodology for reusable seismic frame design in the circular design concept.

2. PRIORITIZING CONNECTIONS FOR THE CASE STUDY

By adopting the reusability principle, the Circular Design Project proposes to create steel frame buildings easier to deconstruct and reuse. Figure 1 depicts the reusability notion in this Project using the Product Life Cycle diagram. The Circular Design subproject, which is part of the HERA Endeavour Research Programme, aims to create more robust data linkages and data distributions between different aspects of the product 4.0 life cycle in order to create more cost-effective and sustainable products for building 4.0.

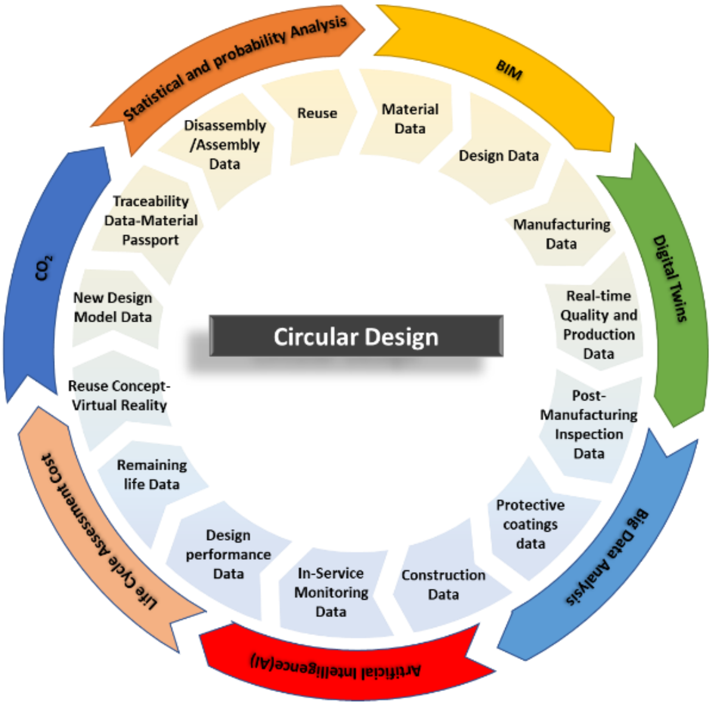

Figure 1: Product 4.0 Life Cycle.

While most basic connections can be bolted, most building frames in New Zealand incorporate multiple welded seismic connections. They can be redesigned with bolted connections, allowing them to be easily disassembled and reused. EBFs frames with fully welded connections, as illustrated in Figure 2, could be modified to fully bolted connections (see Figure 3) by considering the reusability principle for the entire life of the building/material.

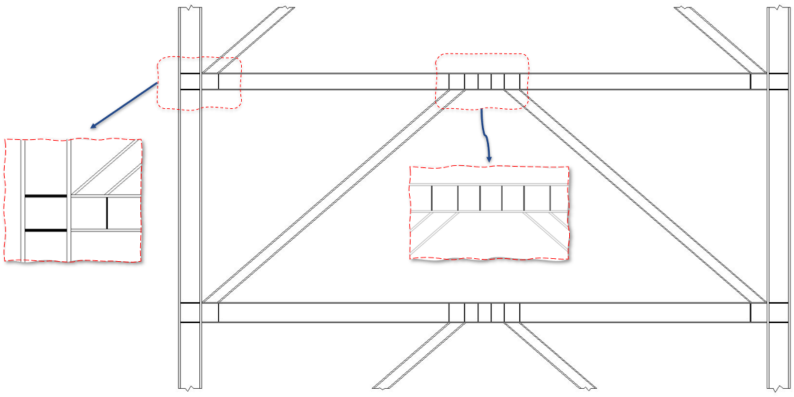

Figure 2: EBFs frames with fully welded connections.

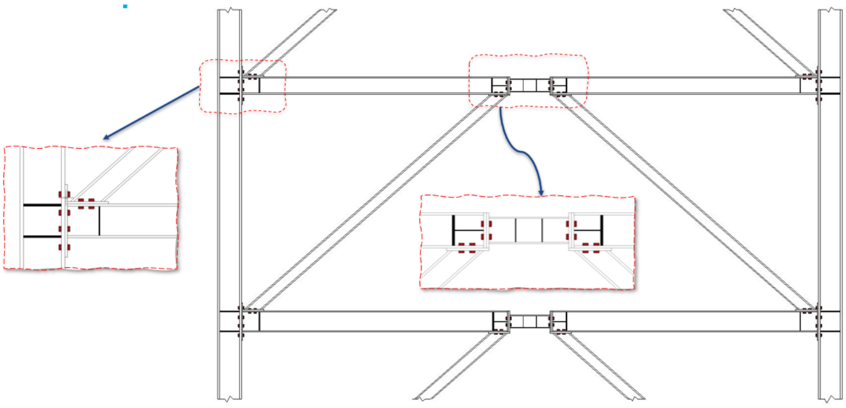

Figure 3: EBFs frames with fully bolted connections developed based on the reusability concept.

Furthermore, from an optimization standpoint, the Circular Design Project prioritizes design/re-design options that reduce production costs. Because New Zealand has a high labour cost, fabrication time (labour time per item) can have a considerable impact on fabrication prices. As a result, it was chosen to begin this investigation by prioritizing and identifying the most desirable connections for optimization. To determine the optimal link for optimization, a questionnaire was created and circulated to fabrication and design consulting firms.

To determine the optimal link for optimization, a questionnaire was created and circulated to fabrication and design consulting firms. The purpose of this survey was to rate structural steel connections based on four criteria: frequency of use, design/detailing work, fabrication cost, and assembly. For the survey, a ranking system of 1 to 5 was established, with 1 signifying a poor choice and 5 indicating an exceptional choice. The poll provided a list of example links that should be voted on, as well as an invitation for respondents to propose more connections that they believe should be included in the questionnaire. The final scores were utilized to prioritize the links for structural optimization as part of the Circular Design Project.

Moment-end plate connections, web-plate connections, and eccentrically braced frames with removable active links received the greatest grades, according to the findings. Due to the fabricator's proposal, it was chosen to begin this research by optimizing eccentrically braced frames with replaceable active links. Although the amount of use of eccentrically braced frames with replaceable active links is minimal, its optimization has a significant impact on cost savings in steel frames.

3. PRELIMINARY DESIGN OF EBF FRAMES

For preliminary design purposes, the member sizes need not be determined at every floor level. It is recommended that the sizing of members be undertaken at every third level for an EBF between 4 and 12 storeys.

In each case, the designer should commence at the first level above the base (seismic ground level). Members at the top level should always be sized explicitly, in addition to the lower floors selected, for this preliminary design process.

Step 1.1. Size of active link

For most EBF configurations, the seismic shear force in the active link (at level *i*) $V_{link,i}$ can be related to the seismic storey shear force in the link level; this relationship is given by the following equation:

$$V_{link,i} = V_i \frac{h_s}{L} \tag{1}$$

where:

$V_{link,i}$ = shear in the active link at level *i* (due to seismic load case *E*),
V_i = seismic storey shear force at level *i*,.
h_s = interstorey height for level *i*,
L = EBF bay width (spacing between column centrelines).

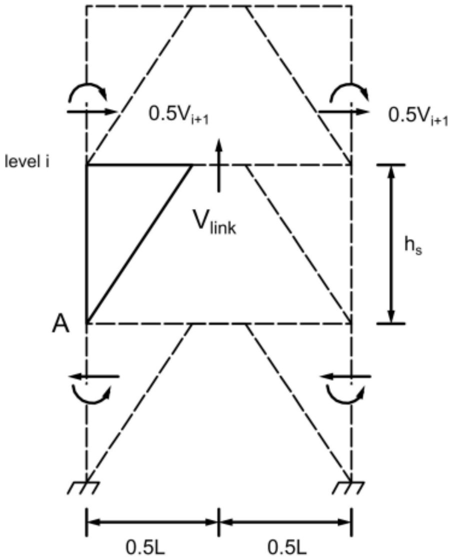

Figure 4: Approximate free body diagrams for estimating active link shear forces for preliminary design of a V-braced EBF

Figure 4 illustrates this relationship for inverted V-braced EBFs. Equation (1) can be derived by considering moment equilibrium about point A at the base of the level *i* column and neglecting the significance of column bending moments.

Step 1.2. Collector beam sizing

For not replaceable shear slink (original EBF (not reusable)), the collector beam section size is generally the same as that used for the active links. For replaceable shear link, the collector beam must be stronger than the shear link. The section size must be checked to verify adequate capacity to resist the capacity design derived actions. Collector beams are subjected to high bending moments with coexistent compression and tension forces, and therefore are required to be designed for combined actions (Section 12.11.7.2 HERA design guide [3]).

The collector beams should be checked for the following combinations of axial force and bending moment:

$$N^*_{beam} = a\frac{\varphi_{oms}V_w}{\tan\theta} \tag{2}$$

where a = 1.0 for replaceable links and a = 0.8 for all other cases.
For EBFs with $d_b < e_{link} \leq 1.6\frac{M_s}{V_w}$:

$$M^*_{beam} = b\phi_{oms}V_w e_{link} + M_{beam,GQc} \tag{3}$$

where:

b = 0.5 for replaceable links and b = 0.4 for all other cases,
ϕ_{oms} = active link overstrength factor,
V_w = nominal shear yield capacity for the active link in the beam,
e_{link} = clear length of the active link,
θ = angle between the collector beam and the brace at the connection adjacent to the active link,
M_s = nominal section moment capacity for the active link,
$M_{beam,GQc}$ = collector beam bending moment adjacent to the active link due to load combination G & Q_c (for a collector beam with simple connections to the columns, supporting a uniformly distributed load, this moment can be estimated assuming $M_{GQc} = w_{GQc}L^2/8$, where L is the length of beam between active link and column).

Step 1.3: Brace sizing

Braces are designed for the capacity design derived actions. The design axial compression force in the braces is given by:

$$N^*_{brace} = \frac{1.15\varphi_{oms}V_w}{\sin\theta} + N_{brace,GQc} \tag{4}$$

where:

ϕ_{oms} = active link overstrength factor
V_w = nominal shear yield capacity for the active link adjacent to the end of the brace
θ = angle between the brace and the collector beam at the connection adjacent to the active link
$N_{brace,GQc}$ = long-term gravity load over the tributary area for the vertical load supported by the brace

The braces are required to be *Category 3* members in *Category 1* and *2* EBFs, and *Category 4* members in *Category 3* EBFs. All braces must comply with the material requirements given in NZS 3404 Table 12.4, the section geometry requirements in Clause 12.5, and the compression load limitations for braces in Clause 12.8.3.1 for the member ductility category appropriate for the structure ductility category. The axial load limitations given by Equation 12.8.3.2 of NZS 3404 do not apply for braces.

Step 1.4: Column sizes in V-braced EBFs

Columns are designed for the capacity design derived actions resulting from active links yielding in shear.

Columns in V-braced EBFs, and columns remote from the active links in D-braced EBFs, are subjected principally to axial forces. The design compression force N_{col} and bending moment M_{col} are given by the following equations:

$$N_{col} = N^{c}_{col} + N_{col,GQc} \tag{5}$$

$$M_{col} = 0.15\phi_{oms}V_{w}e \tag{6}$$

where:

N_{col} = column seismic axial force for load case E_u,

N^{c}_{col} = seismic induced axial force given by $\sum_{i}^{n} \phi_{oms} V_w$ (but does not need to exceed $N_{col,E}C_{max} / C$),

$N_{col,GQu}$ = column axial compression at the level under consideration,

C = lateral force coefficient for design seismic loading,

C_{max} = lateral force coefficient for maximum seismic load,

e = nominal eccentricity from column centreline for simple connections.

4. CONCLUSIONS

Industry 4.0 concepts are utilized in this research project to assist the construction industry in transitioning to a more technologically advanced sector. The primary purpose at the moment is to develop a methodology for reusable seismic frame design with the circular design idea. The steel used is lighter when welded structural specifications are optimized, whether in terms of weight or cost. Because mass has a direct relationship with global environmental impact, reducing mass leads to a reduction in environmental impact. Welding technology or electrodes' environmental impact is also influenced by the size of the weld, i.e. indirectly through mass. In this project, mixing reuse with optimization a competitive structure will be created.

5. ACKNOWLEDGEMENTS

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