WAREHOUSE REVIEW FINDINGS REPORT

February 2023

EXECUTIVE SUMMARY

Following the Masterton buildings inquiry, Engineering New Zealand Te Ao Rangahau commissioned a review of 20 warehouses across New Zealand to understand if issues of poor design quality observed in the Masterton cases were seen elsewhere.

The results of the Warehouse Review suggest issues relating to poor design and internal quality control seen in the Masterton buildings are not isolated. Some design engineers are incorrectly designing or leaving out critical details in their design of warehouses; for example the restraint of large concrete panels. Inadequate restraint of a panel may present a life safety risk if it were to collapse in an earthquake.

As a result of this review, Engineering New Zealand will partner with collaborating technical societies and other relevant organisations to provide guidance for better engineering practice as it relates to warehouse design. We will work with stakeholders to disseminate the guidance and educate engineers.

This report is intended for engineers and building consent authorities. If you own a warehouse and have questions about its design, please contact a Chartered Professional Engineer for review.

CONTENTS

INTRODUCTION

Engineering designs are not routinely audited for technical compliance to the Building Code after a building has been constructed. Once designs have been consented and built, potential problems can be challenging and costly to resolve.

Although the Structural Engineering Society of New Zealand (SESOC) has been calling for technical audits of engineers' work since 2007, there is no systemwide process for reviews by building consent authorities (BCAs), the Ministry of Business, Innovation and Employment (MBIE) or industry.

In November 2021, Engineering New Zealand commissioned a high-level screening review by five expert engineers of the design of 20 warehouses throughout the country to test whether findings from the Masterton Buildings inquiry were isolated.

Masterton buildings inquiry

In 2015, concern was raised with Engineering New Zealand about the structural integrity of six warehouse buildings owned by the Masterton Trust Lands Trust. Post-construction reviews found the buildings failed to comply with relevant structural standards at the time of design, potentially falling short of the Building Code. Professional disciplinary processes were taken against the Chartered Professional Engineers who signed off on the buildings.

Structure of this report

This report has three sections. The first describes our process for selecting the warehouses and the results from the expert review engineers' analysis. Important and recurring themes are discussed, followed by conclusions and recommendations.

The second and third sections of this report are instructional. The second section provides examples of poor design and illustrates principles engineers should consider in their design. Its purpose is to help engineers learn and improve their practice. The final section lists supplementary resources.

This report is intended for engineers and building consent authorities. Owners with questions about the design of their warehouse should contact a Chartered Professional Engineer for review.

APPROACH

The 20 warehouses in this sample are spread across the country. Nineteen of the warehouses were built since 2000 and one was built in the late 1990s.

All warehouses were sufficiently complex in that engineers must use good engineering principles in their designs. At the same time, all designs could be checked quickly by an experienced engineer due to their relatively simple skeletal structures. In each case, the original design approved by the BCA was signed off by a Chartered Professional Engineer.

Although we have tried to ensure the sample is representative of this building typology, the sample is too small to be of statistical significance. Further, no nationwide register of buildings exists from which to draw a controlled sample. However, this study attempts to provide some quantitative evidence for anecdotal reports that issues with warehouses are occurring throughout New Zealand.

Process

To mitigate bias, the warehouses included in this review were randomly selected by a staff member at Engineering New Zealand with no interest in the project. Consenting documentation for the 20 warehouses included in this review were provided by the six relevant BCAs.

Engineering New Zealand and an external expert engineer have developed a template for reviewing engineers to complete (Appendix 1). This simple template highlights potential issues in the buildings to assess for robust design.

Reviewing engineers were not asked to undertake detailed calculations of the buildings or its components. As a result, buildings and components are classified broadly as 'good', 'average' or 'poor'. Graphical representations of what these terms indicate are provided in the second section of this report.

Our reviewing engineers were only given information from BCA files. They did not use as-built drawings or other information such as photographs or site visits, and therefore had the same information as did the BCAs approving the designs.

Assessing for compliance with the Building Code was out of scope. Fire engineering design was also outside the scope of this review.

A note about Design Features Reports (DFR)

A DFR allows a reviewing engineer to ascertain how the engineer designed the building and the engineer's assumptions. It also forms a basic checklist for an engineer to ensure their design is robust. DFRs were brought into use as good practice by SESOC in 2010, and their use has been encouraged by MBIE, the New Zealand Construction Industry Council (NZCIC) and Engineering New Zealand. DFR templates are available to download for free from the Engineering New Zealand website.

We were provided with only one DFR for the designs included in this review.

RESULTS

The results of the expert engineering reviews of the 20 warehouses show two underlying issues:

1. Inadequate consideration of load path
2. Inadequate detailing of connections.

Table 1 shows the consolidated results of the warehouse buildings reviewed. Performance on common themes is identified and implications provided in our discussion.

Table 1: Key results of the warehouse review. Common review themes are identified, with performance being graded as good, average or poor (see Appendix 1 for an example of good, average and poor detailing).

Common review themes	Good	Average	Poor
Foundation design	55%	23%	23%
Baseplate connections	59%	18%	23%
Concrete panel anchorage	23%	32%	45%
Panel restraint from falling	23%	32%	45%
Knee detailing	64%	23%	14%
General detailing of connections	18%	50%	32%
Differential movement	23%	55%	23%
Restraint against buckling	45%	32%	23%
Bracing detailing	23%	36%	41%
Bracing capacity	18%	41%	41%

DISCUSSION

Foundation design

Current practice is to base the foundation design on information in a geotechnical report. The main problems identified in the reviews involved undersized foundations and lacking sufficient pull-out capacity for anchors.

Baseplate connections

Reviews identified a common lack of detailing about the anchorage of the baseplate to the slab. Some of the portals were likely modelled as having a fixed base which exacerbates their detailing inadequacies dramatically.

Concrete panel anchorage

Reviewers identified that panel anchorage frequently is poor at the base. After the Canterbury Earthquake Sequence, SESOC raised concerns about the performance of cast-in anchors. Subsequent testing by the University of Auckland has since found that performance was less than expected, and the failure mode was brittle cone pullout[1]. In two examples since 2016, cast-in anchors had been specified, even though concerns had been raised about such anchors and the information widely circulated by this time.

Panel restraint from falling

A key theme here was insufficient restraint preventing concrete panels from falling inwards or outwards. Transom beams (which are used to connect concrete panels to portal frames) should be restrained against buckling. However, the reviewers typically found universal beams, columns, and parallel flange channels had been specified, albeit without torsional restraint. Where detailed, they were often secured by non-seismic rated bolts. In several buildings there were no details on how panels were to be secured to the portal.

Knee detailing

The weld detailing of the knee was typically sufficient. However, there was rarely any lateral restraint to the knee or column, which could result in steel portal frames buckling in an earthquake.

General detailing of connections

Poor detailing was a common feature, with many designs having unclear connection details for bracing systems, or connection details entirely missing.

Differential movement

Designs did not typically allow for concrete shrinkage and movement. However, the reviewers were satisfied that in most cases this did not amount to a life safety issue.

Restraint against buckling

Of all the designs reviewed, only one portal leg was detailed for buckling. There were typically details for fly-braces on the portal rafters, but the spacing was not always clear.

Bracing detailing and bracing capacity

Reviewers looked for 'robustness' – where the structure has sufficient redundancy to adapt if a load path does not perform as expected. Roof bracing in the longitudinal direction of the warehouse was typically poorly detailed, reducing the capacity for cross bracing. There were incomplete load paths, eccentric cleat design, and bracing missing completely.

1 Hogan, Henry and Ingham, 2017 cdn.ymaws.com/concretenz.org.nz/resource/resmgr/docs/conf/2017/34.pdf

CONCLUSION

Engineering New Zealand commissioned this review to examine the extent of issues signaled in the Masterton building inquiry and to consider measures to mitigate issues identified. The results suggest those issues relating to poor design and internal quality control seen in the Masterton buildings are not isolated.

In some cases, engineering designs have not addressed key structural design elements, including those that ensure load paths and detailing are able to withstand seismic activity. In some examples, design engineers had incorrectly drawn or omitted critical details in their design of warehouses, such as the restraint of large concrete panels, which may present a life safety risk should they collapse during an earthquake. Further, such issues appear to have been present in the building system for some years, including MBIE determinations relating to poor warehouse design (Determinations 2013/057[2] and 2016/003[3]).

The results of this review provide a compelling case for educating engineers and BCAs about issues with current design practice regarding warehouses, and for upskilling engineers in a robust design approach when designing warehouses. This report informs that education, with examples of good, average and poor design work provided, as well as additional resources to support engineers in their work.

RECOMMENDATION

We recommend building on the work of this review with a focus on educating engineers, including structural engineers involved with warehouse design to take guidance from SESOC's 'Ten tips for better design of low-rise structures' seminar series and the New Zealand Geotechnical Society, New Zealand Society for Earthquake Engineering and SESOC's 'Earthquake Design for Uncertainty'.

NEXT STEPS

Engineering New Zealand will partner with collaborating technical societies and other relevant organisations on design guidance for warehouses, emphasising attention to load paths and connection details. We will work with stakeholders to disseminate the guidance and incorporate it into engineering practice. We will continue to look for opportunities to educate engineers about the issues identified in this review.

We will also work with the Ministry of Business, Innovation and Employment to understand how this review's findings and any design guidance might inform future regulation.

As the Registration Authority for Chartered Professional Engineers, as well as the professional body for engineers, Engineering New Zealand is well placed to lead or assist these initiatives.

2 www.building.govt.nz/assets/Uploads/resolving-problems/determinations/2013/2013-057.pdf

3 codehub.building.govt.nz/resources/2016003

APPENDIX 1: REVIEW TEMPLATE

Project address: ______________________________

Typology (eg full height shear walls, partial height walls): ______________________________

Provide succinct one sentence answers where possible.

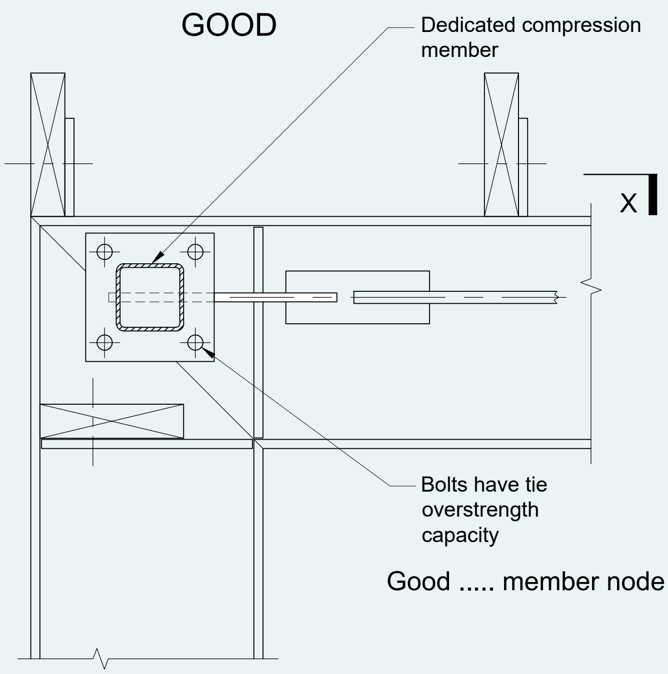
Across direction	Description or snip	Is this in line with good practice?	If not, why not?
Do the foundations appear to be sufficiently robust for the loads?			
How robust is the baseplate detailing. Typically pinned connection.			
How are the concrete panels anchored to the slab?			
How are the concrete panels restrained from falling?			
Do the connections appear to be seismically rated?			
How are the panel connections detailed to avoid eccentricity?			
How robust is the detailing?			
How robust is the knee joint? A single diagonal stiffener is typically insufficient.			
How has differential movement between the portals and panels been accounted for?			
How have the columns and rafters been restrained against buckling? Is it sufficient?			
What is the span to depth ration of the portal?			
Additional comments			

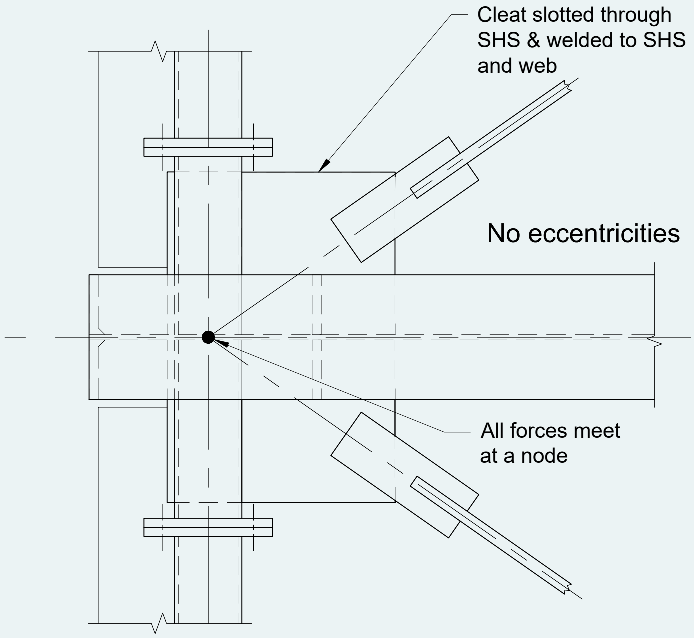
APPENDIX 2: **DESIGN EXAMPLES**

We recommend all design and reviewing engineers pay close attention to the concepts of good, average, and poor practice outlined in this section of the report. The principles are the same for all critical detailing errors observed: follow the load path, ensure capacity exceeds demand, and avoid eccentricity.

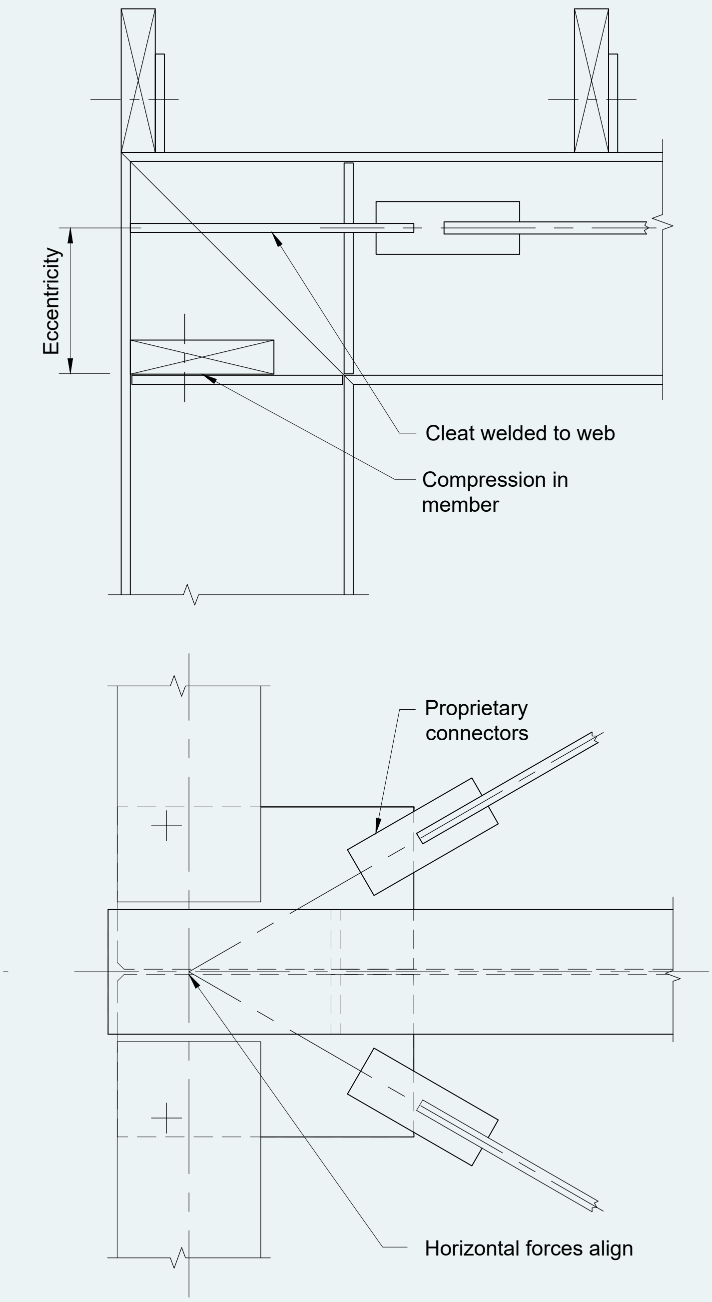
For a design to be effective, it must fulfil the client's needs, have clear and robust load paths, and the contractor must be able to build it. Clear concept drawings and details help ensure that all three requirements are met.

The diagrams and descriptions below are provided so that engineers can learn from issues observed in warehouse design. Further examples of good practice will be provided in subsequent design guidance. Until that guidance is available, we recommend engineers review this report's 'Useful Resources' section and watch SESOC's '10 Tips for Better Design of Low-rise Structures'. SESOC is making the handbook and webinar recording available at no cost.



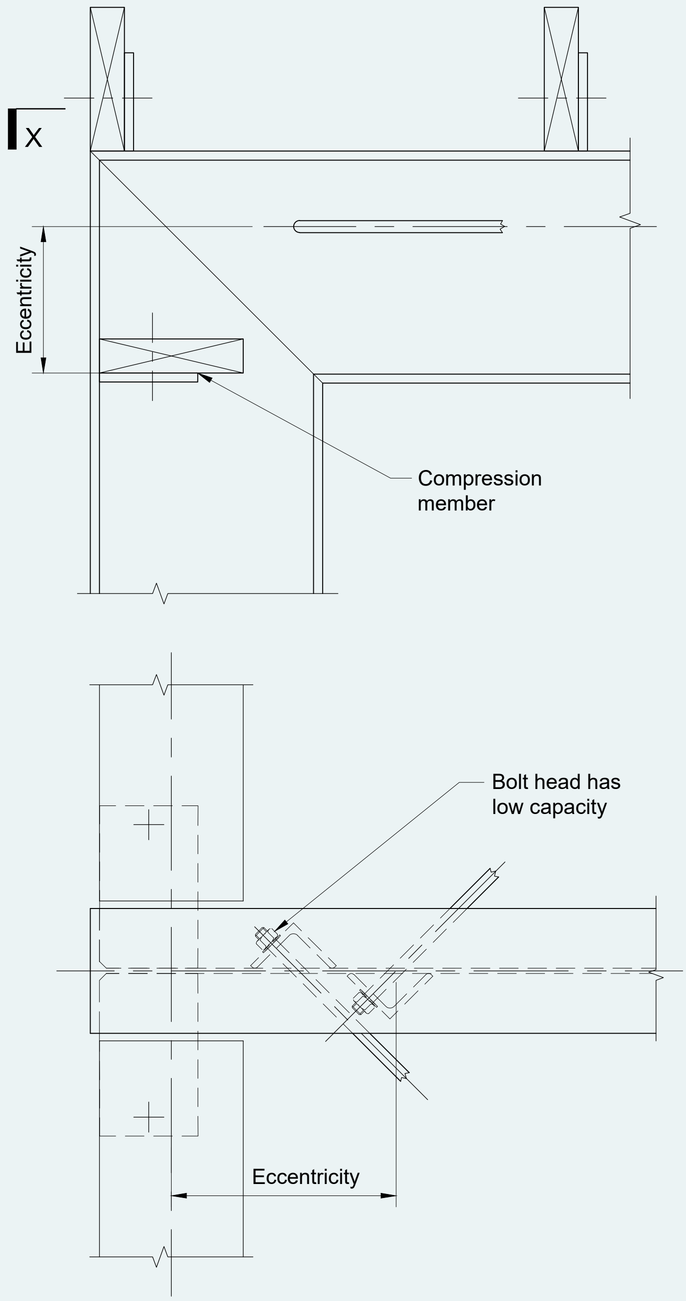


AVERAGE



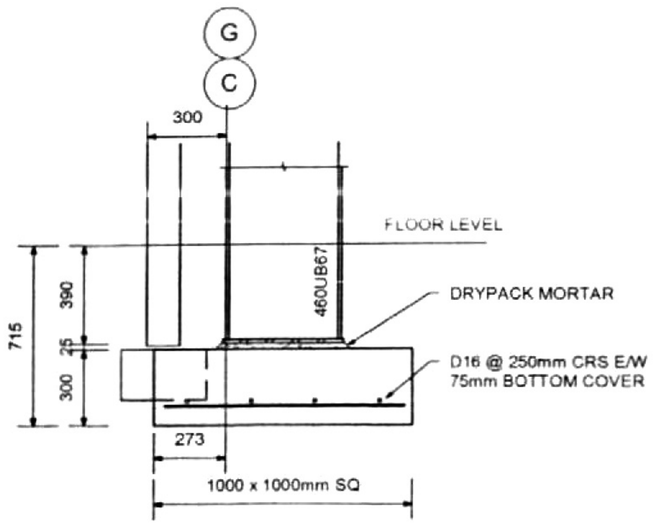
VIEW X-X

BAD


X
Eccentricity
Compression
member
Bolt head has
low capacity
Eccentricity

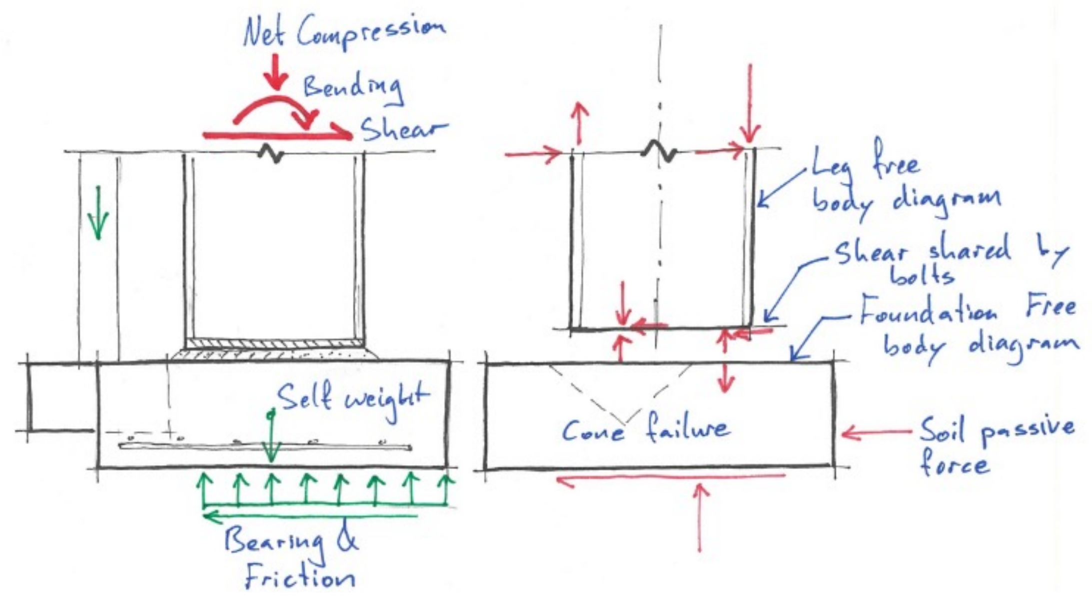
The following examples of design detail are used to show examples of poor practice. These examples are drawn primarily from warehouses included in this review. Where possible, we have included examples of good practice from SESOCs '10 Tips for better design of low-rise structures'.

1. Foundation design



What is happening in this detail?

This detail shows a shallow pad supporting a portal frame. Typically, the assumption for portal frames is that they have a pinned base. A pinned foundation base implies rotation, and the bolts must still have some tension capacity. A tension failure in the bolt will cause it to lose shear-carrying capacity, overloading the other bolts in the system.



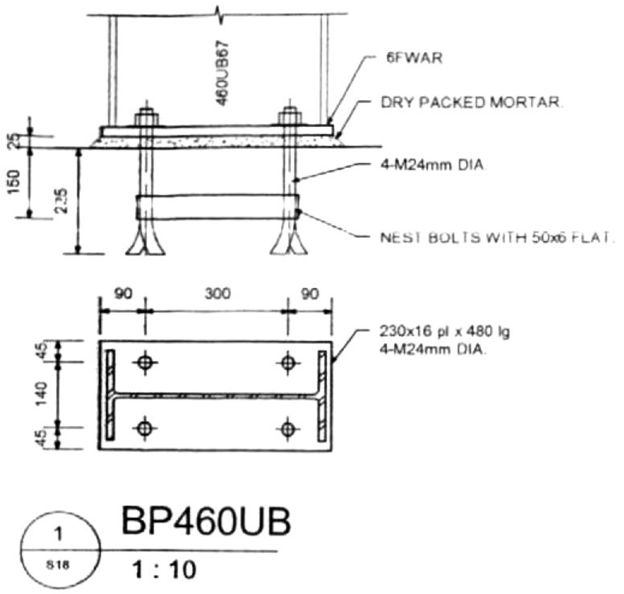
Why is this poor practice?

Consider the load path. Reinforcing steel provides resistance to tension forces in concrete. Bottom steel in the slab or edge beam will provide resistance to a downward force from the portal leg, but how is the tension force from the hold-down bolts resisted?

Learning points

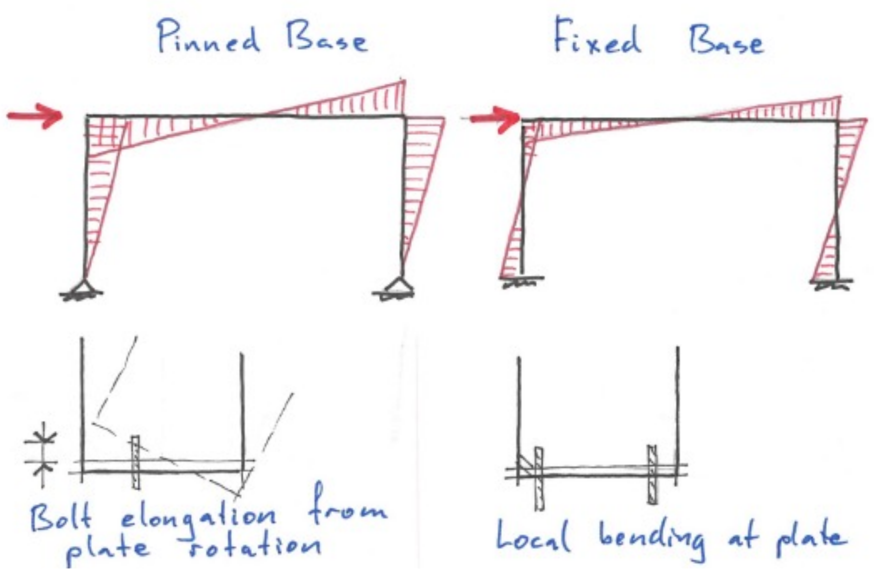
- There is no top reinforcing on the pad footing. There should be a cage to resist tension forces.
- Where in the drawings does one look for other pertinent build information such as baseplate detailing?

2. Baseplate detailing



What is happening in this detail?

The two boundary assumptions that can be made for portal frame design are fixed bases or pinned bases. Designing a portal frame to behave as a pinned base requires the baseplate or the bolts to accommodate a rotation at the base.



Why is this poor practice?

Consider the load path. This baseplate is insufficiently strong or stiff to be a fixed connection; therefore, the engineer expects a pin base to form. With the bolts so close to the flanges, that is unlikely. Instead, a moment connection will form at the base with prying forces acting on the bolts.

With the moment connection developing as the portal cycles, tension and compression forces are transmitted to the baseplate through the flanges in the column. What will the failure mechanism be? Will it be a ductile failure? For a ductile failure to occur, the bolt and baseplate strength must exceed that of the portal leg since yielding will always occur in the weaker component in a joint. It is unlikely that a plastic hinge will develop in the universal beam (UB) before either the bolts, weld or baseplate fail.

Dry-packed mortar should not be used in industrial portal frames. Pourable grout is preferable.[4]

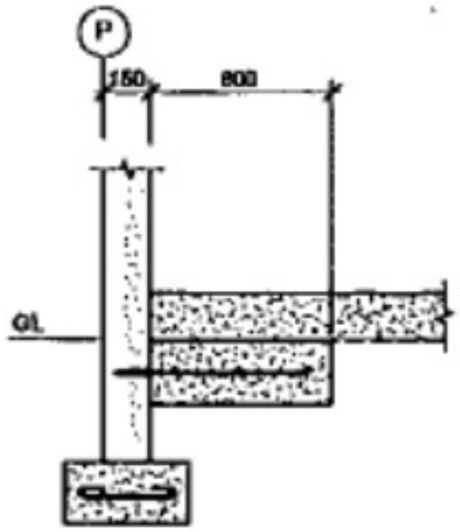
Learning points

- The weld from the UB to the plate is likely to be the weakest link. Consider the forces on the flanges as the portal cycles.
- The 16mm base plate will likely fail in plate bending.
- The bolts will try to form a fixed base due to their lever arm (see 'Anchor Bolts for Steel Structures' by Scarry[5], available from SESOC).
- The engineer has not considered tension forces in the concrete and should have embedded the bolts in a cage (see foundation design above).

4 See Design of Portal Frame Buildings, Woolcock et. al., section 7.9.3 www.steel.org.au/resources/elibrary/resources/introduction-to-the-design-of-portal-frame-buildings-bk180

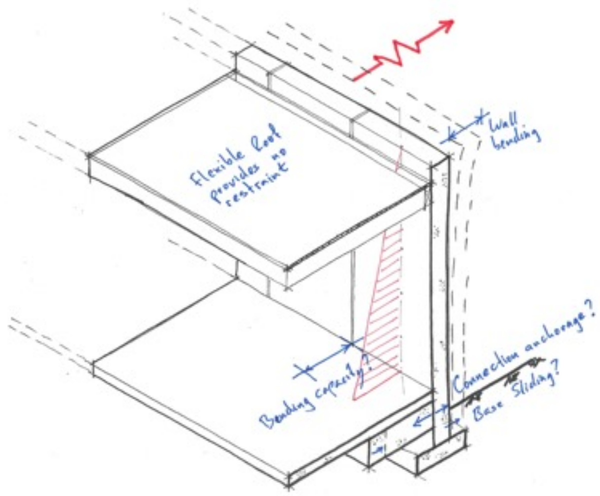
5 www.sesoc.org.nz/design-resources/guidelines/anchor-bolts-for-steel-structures-draft-design-guide

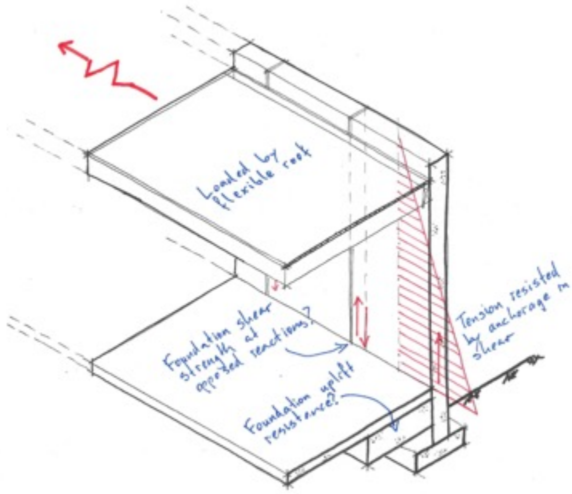
3. Concrete panel anchorage



What is happening in this detail?

This is a structural wall for a lean-to extension to the main portal spans. The panel supports a lightweight roof. The panels appear to carry gravity and lateral loads, and due to the flexible roof, they must take these loads in-plane and out-of-plane. The panels may have been adequately designed for the load-paths illustrated below, but they cannot be built to match the detailed design without better drawings.





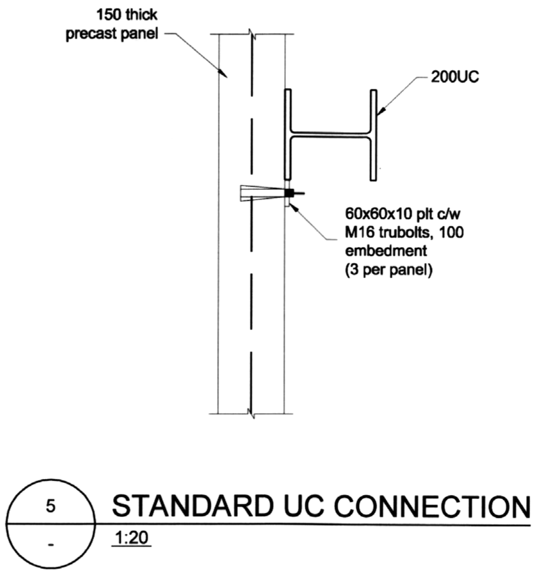
Why is this poor practice?

This is a representation of poor drawing and poor anchorage. These are the drawings that the engineer submitted to the council for building consent. The builder likely received the same plans for construction. As the reviewing engineer, how can you check that the design meets its requirements?

Learning points

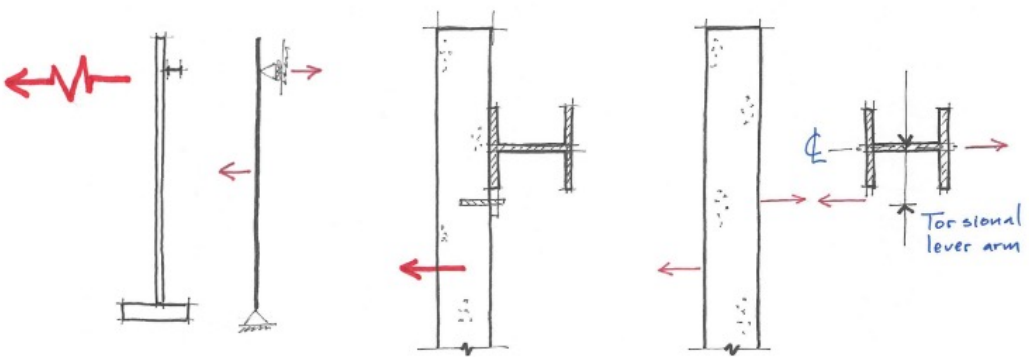
- Where are the dimensions for the builder?
- How will the panel resist forces?
- What type and size of reinforcing is required? At what spacings?
- How is the reinforcing anchored in the panel?
- There is no way for a reviewing engineer to check this detail or a contractor to build it.

4. Panel restraint from falling



What is happening in this detail?

This detail is intended to restrain the out-of-plane forces experienced by a precast panel attached to a building. The panel spans vertically from the base to the universal column (UC), and the UC spans horizontally between portal frames.



Why is this poor practice?

This engineer had considered the load path and provided for a beam in the design but the detailing was poorly considered. There were examples of no restraint at the top of the panel.

Always consider eccentricity and torsion when designing connections and load paths. How torsionally sensitive is a UC or UB (universal beam)? If this were a beam, would you apply a point load in this manner without (as a minimum) providing torsional restraint? How would you overcome this problem?

There are now Trubolts rated for seismic design, but it is unlikely they were at the time. Consider that these panels are subject to loadings through Parts and Portions. Therefore, the engineer should specify a restraint that has a seismic capacity.

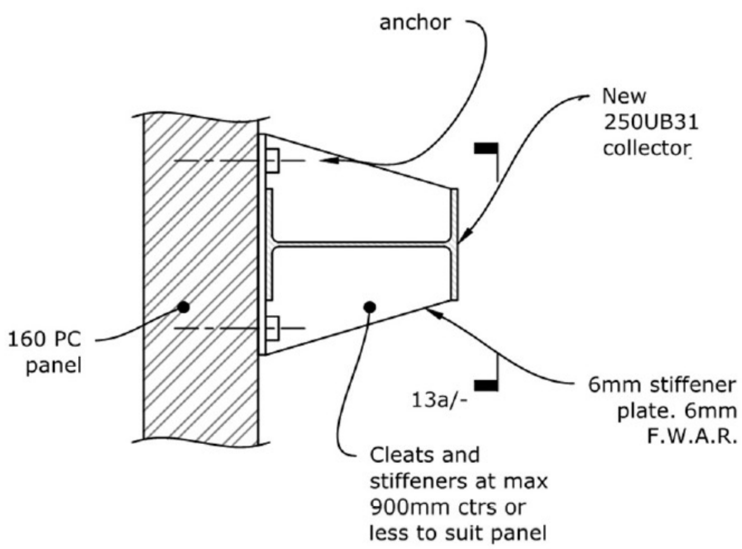
Learning points

The failings in this example are as follows.

- The UC used as a waler is eccentrically loaded.
- The lack of torsional restraint is likely to cause a buckling failure in the beam.
- The anchors are not seismically rated.
- Ensure anchors are sufficiently embedded to develop full capacity, as per the manufacturer's specifications.

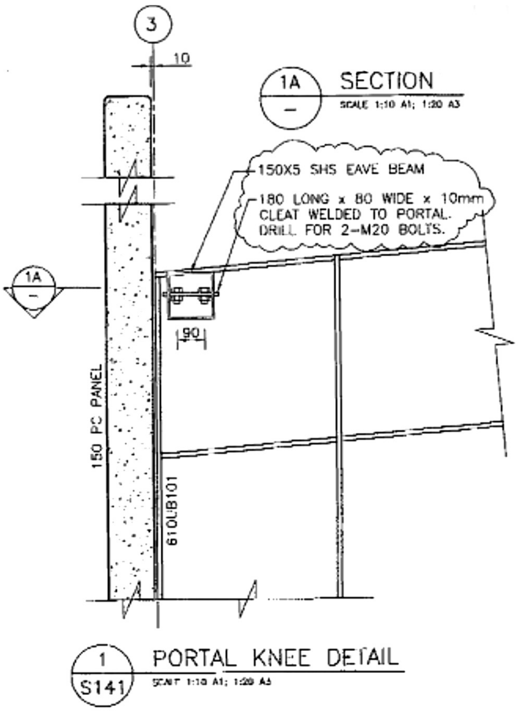
Example of better detailing

Figure 1: Example supplied by Grant and Hughes (10 Tips for Better Designs of Low-Rise Structures).



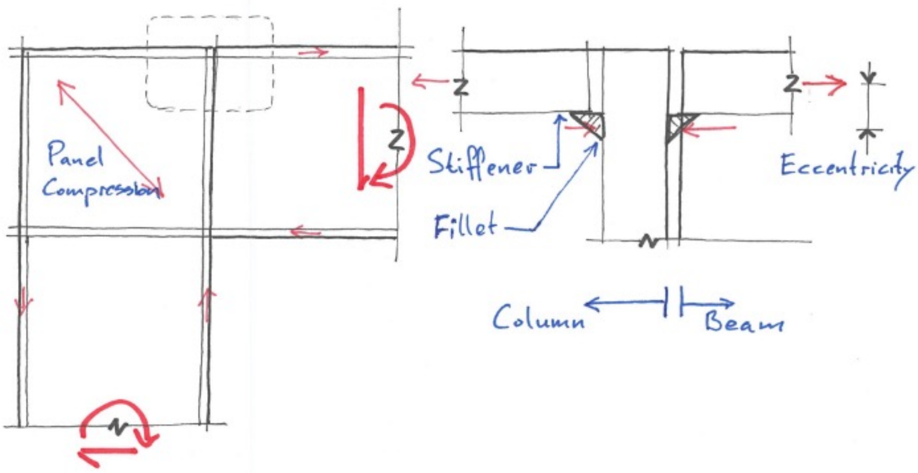
Here, the collector beam has been designed as a part as per MBIE determination 2013/057. The beam also has rotational restraint and can yield.

5. Knee detailing



What is happening in this detail?

This is a moment-resisting knee joint in a portal frame. Most general notes drawings specify 6mm fillet welds 'unless noted otherwise'. The beam might be continuous, or the column. Either way, the details of the tension flange rely on the welding to transmit the full tension force from the flange.



Why is this poor practice?

For a design to be checkable and buildable, the engineer and draughter must label it clearly. What sizes are the stiffeners? How can you be sure that the stiffeners can carry the entire force in the flange across the knee?

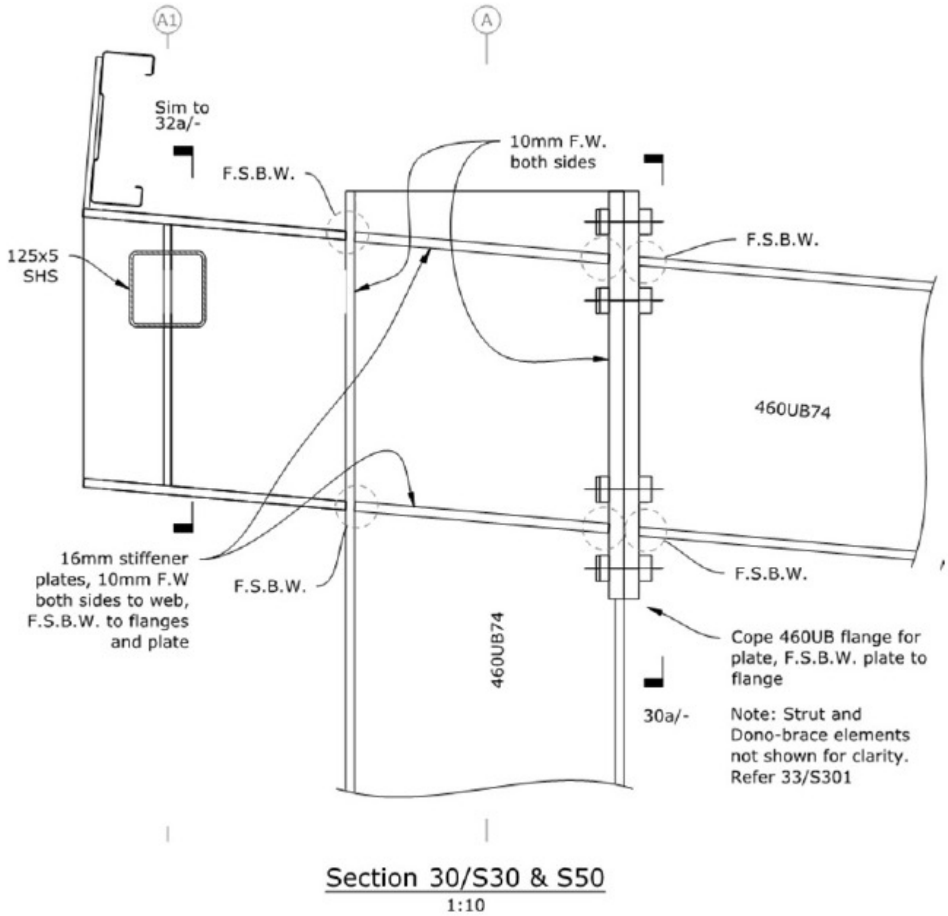
What type of weld is holding the knee together? Significant forces travel around the knee; could a 6mm fillet weld hold the flanges together? If the manufacturer used a fillet weld that wasn't suitable, who is liable for the rework?

Learning points

- The lack of detailing means there is no way of telling if this is a robust knee.
- Non-destructive testing requirements for welding should be included on the drawings, as per Appendix 1 tables in NZS 5131.

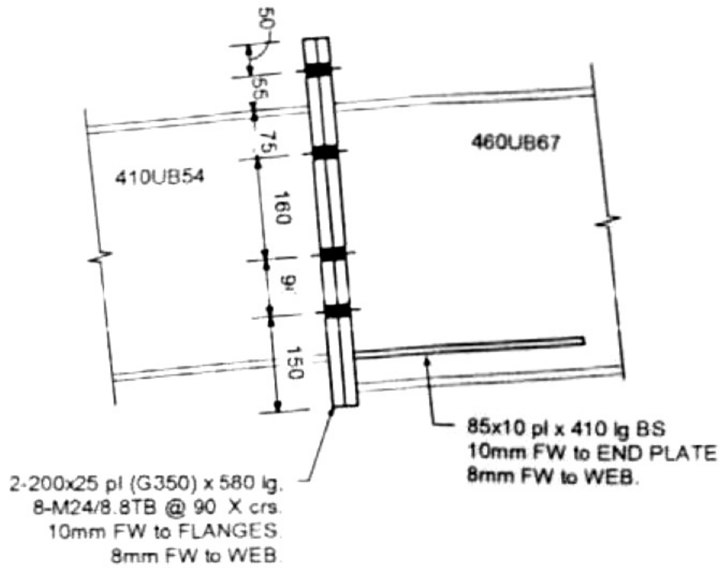
Example of better knee detailing

Figure 2: Example supplied by Grant and Hughes (10 Tips for Better Designs of Low-Rise Structures)



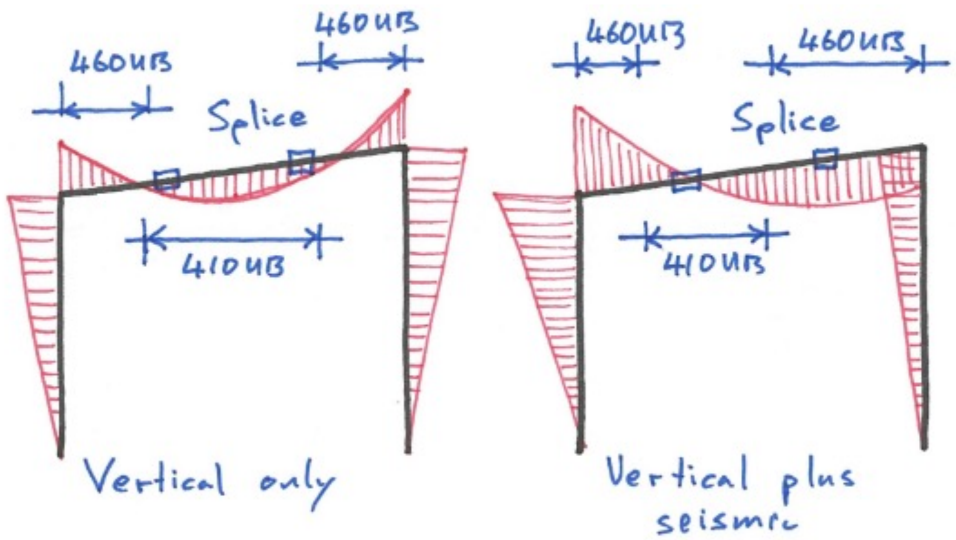
This knee joint was designed to the SCNZ Steel Advisor – Moment End Plate – Column Side (CON1001) principles. It is clearly detailed and contains enough information for construction and checking.

6. Splice



What is happening in this detail?

The designer has reduced the section size away from the ends of a portal frame to economise on the total steel tonnage. Typical portal-frame spans have similar bending moments at mid-span to the knee joints, making this kind of detail impractical. Assuming that the gravity design results in a smaller net bending moment in the centre than the knee joints, the extent to which a smaller member is suitable will change under lateral loading.



Why is this poor practice?

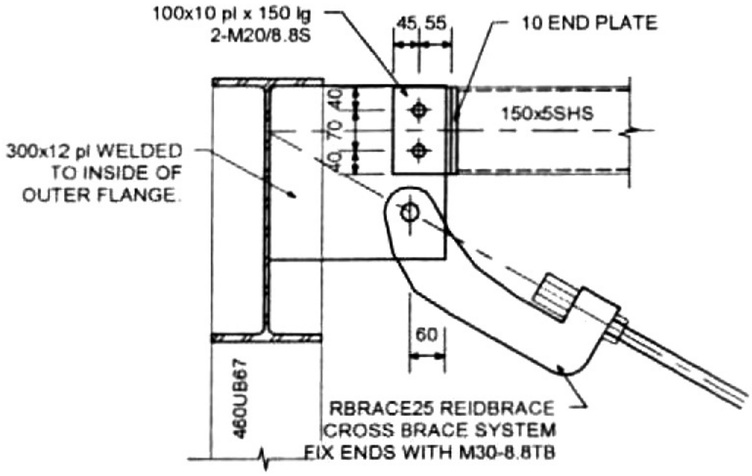
It appears the engineer has considered when the portal cycles one way but not the other. What will happen when a tension force is generated in the bottom flange?

Consider the potential load in the flange $190\text{mm} * 12.7\text{mm} * \frac{300N}{\text{mm}^2} = 724kN$ with a 75mm lever arm. That gives $\text{M}* = 54.3kN\text{m}$. What is the capacity of the end plate?

Learning points

- Follow the load path. How will the joint transfer tension force in the bottom flange? The plate would need to bend to the first bolt.
- Think about the space the welder has to get the stick between the flange and the plate. Is there sufficient space to complete the required welding? Draw out the section and see if it seems realistic to you.

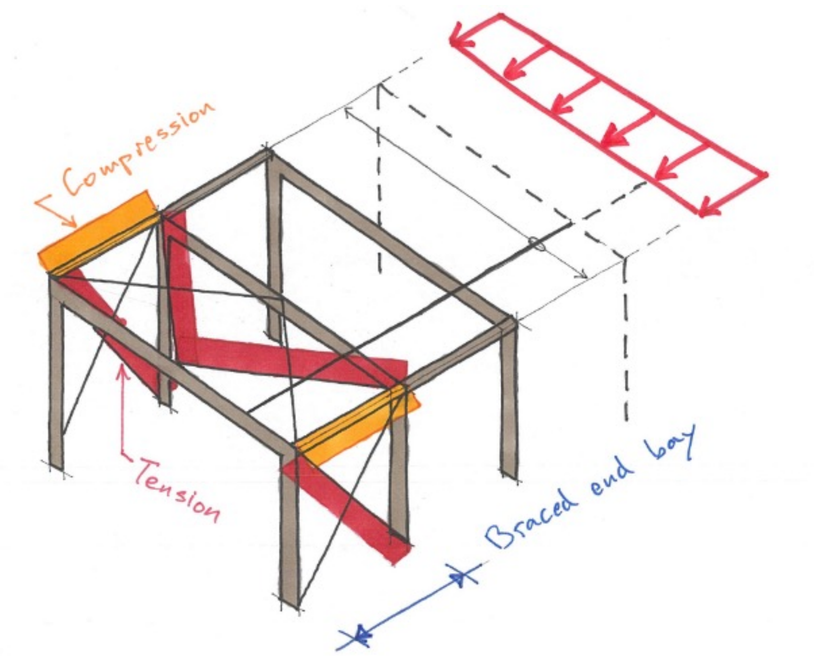
7. Bracing detail



What is happening in this detail?

This detail shows the connection between roof and wall tension bracing. The building experiences seismic loads as a distributed force over the whole surface of the building. These loads are collected into diagonal bracing in the plane of the roof and walls and then into diagonal wall bracing to the foundations. These tension loads are transferred via a compression strut at the wall top.

Typically, steel framed buildings are only braced in a limited number of bays, so these concentrated loads could be equal to the total base shear of the building. The accidental eccentricity requirements of 1170 mean that each side wall should be designed for over half the base shear, and even when a 'nominal ductile' approach is taken, design robustness means the connections should be designed for a higher load level than the connecting members to ensure a brittle failure doesn't occur.

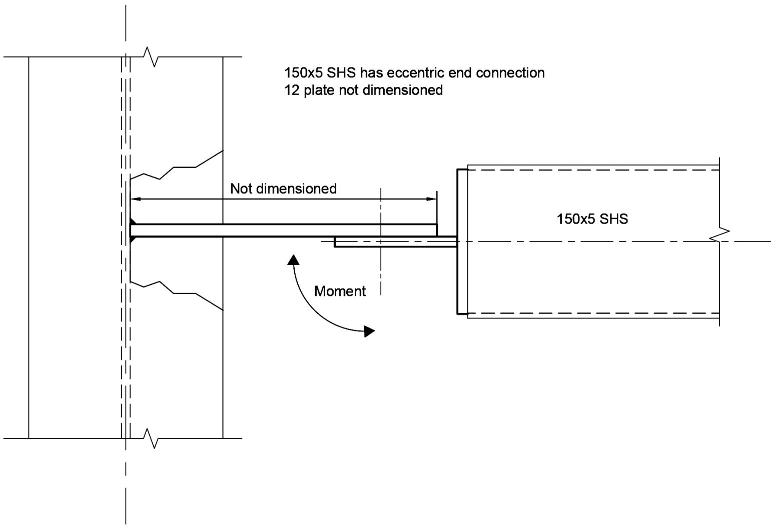


Why is this poor practice?

There should always be a viable load path. A viable load path means that all the forces should be collected and transferred into the ground. Connections must be able to work in both tension and compression. Engineers must work with draughters to understand how to detail connections while avoiding eccentricity.

Learning points

- Follow the load path. There is an eccentric cleat in compression. How would you detail the connection to avoid eccentricity?



Examples of good detailing:

Figure 3: Eliminate eccentricity. Example supplied by Grant and Hughes (10 Tips for Better Designs of Low-Rise Structures)

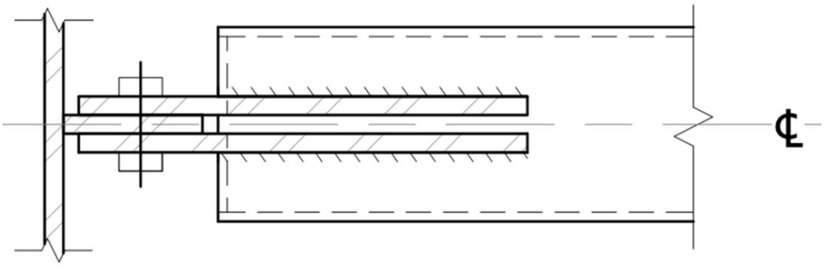
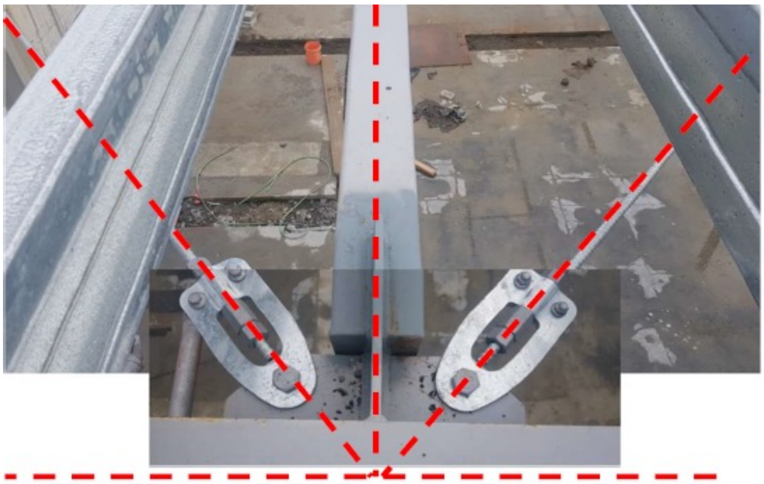
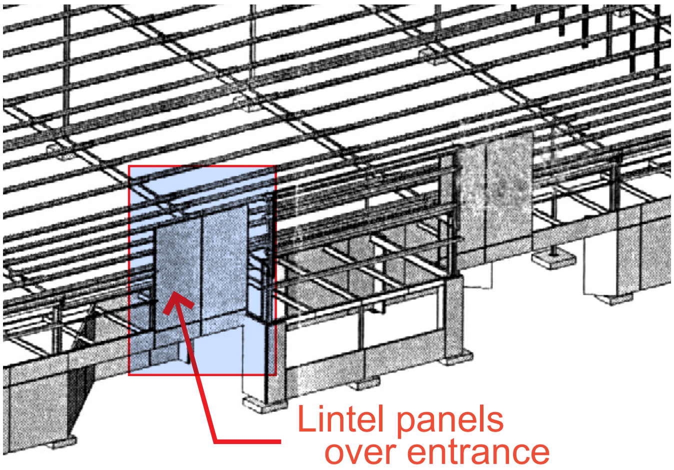


Figure 4: Consider load transfer - keep detailing simple. Example supplied by Grant and Hughes (10 Tips for Better Designs of Low-Rise Structures)

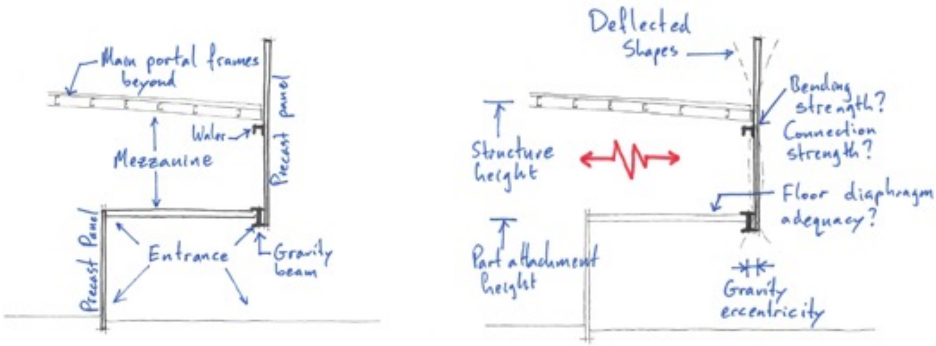


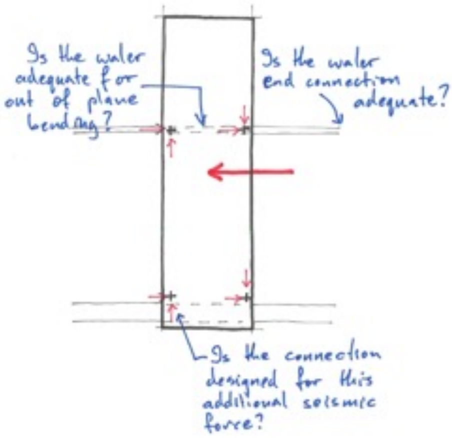
8. Consideration of load path



What is happening in this detail?

These panels frame the entryway, creating an oversized space for signage. The precast panels are supported by steel beams via equal-angle stubs with a single M16 bolt through an endplate.

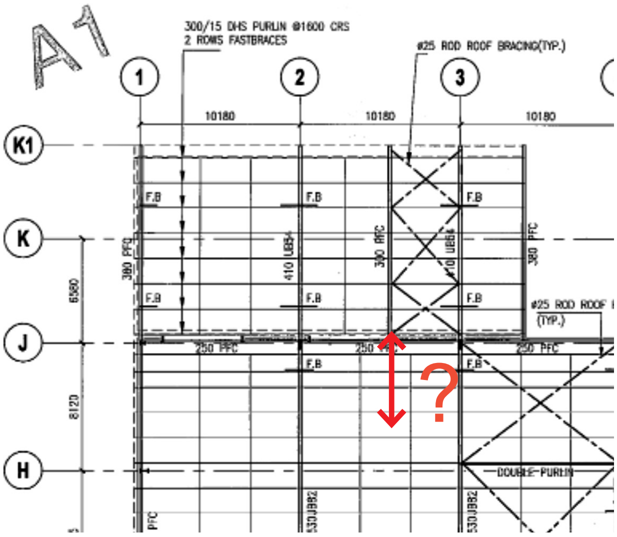




Learning points

- Follow the load path. These are precast concrete panels in a high seismic zone. Think about the panels rocking side to side and back and forth directly over the entrance. What is supporting them? Would reinforced concrete have been the best choice for these panels?
- Everything depends on the robustness of the connections.
- What time-dependent effects are likely as these panels cycle out of phase?

9. Bracing load path



What is happening in this detail?

This roof bracing is intended to connect the outer lean-to wall to the main structure.

Why is this poor practice?

There must be a continuous load path to the ground. A continuous load path is essential because it helps redistribute outside pressures or forces caused by earthquakes and high winds, transferring these external forces from the frame to the foundation and into the ground.

If a load path is not continuous, the forces will travel through unexpected ways and possibly cause damage in unforeseen areas.

Learning points

- Follow the load path from the struts. How are the compression loads getting to the foundations?

USEFUL RESOURCES

Documents providing information and guidance on the design of warehouse-type buildings in New Zealand (excluding floor and foundation design guidance).

Australian Institute of Steel Construction

Woolcock, S.T., Kitipornchai, S., & Bradford, M.A. (1999). Design of Portal Frame Buildings (3rd ed). Australian Institute of Steel Construction.

Hyland, C. (2010, April 27). Gen 7001 Portal Frame Design Tips Seminar Proceedings. Steel Construction New Zealand Inc. www.scnz.org/wp-content/uploads/2020/12/GEN7001.pdf

Fussel, A. (2009, March 17). MEM 3601 Deep Rafter Stability. Steel Construction New Zealand Inc. www.scnz.org/wp-content/uploads/2020/12/MEM3601.pdf

Australian Steel Institute

Author. Australian Steel Institute. (2018). Lateral Buckling Design of Portal Frame Rafters. Australian Steel Institute. www.steel.org.au/resources/elibrary/resources/lateral-bucking-design-of-portal-frame-rafters-sc_

BRANZ

Beattie, G. J. (2007). A Guide for Designing and Detailing Slender Precast Panels for Earthquake Load Resistance. Building Research Association of New Zealand (BRANZ). cdn.ymaws.com/concretenz.org.nz/resource/resmgr/docs/conf/2002/s5_paper_2_-_beattie.pdf

Concrete New Zealand

Restrepo, J.I., Crisafulli, and Park, R. (1996). Seismic Design and Behavior of Tilt-Up Buildings. The New Zealand Concrete Society: Making Innovations Happen Conference. cdn.ymaws.com/concretenz.org.nz/resource/resmgr/docs/conf/1996/s5_p1_-_restrepo_crisafulli_.pdf

Poole, R.A. (2005). Report to Department of Building and Housing: Design and Construction of Slender Precast Concrete Walls. www.mbie.govt.nz/dmsdocument/68-concrete-walls-report-pdf

HERA

Clifton, C. (1997). HERA Report R4-92: Restraint Classifications for Beam Member Moment Capacity Determination to NZS 3404. NZ Heavy Engineering Research Association (HERA). www.hera.org.nz/product/hera-report-r4-92-restraint-classifications-for-beam-member-moment-capacity-determination-to-nzs-3404

Clifton C., Mago, N., & El Sarraf, R. (2008). Eccentric Cleats in Compression and Columns in Moment-Resisting Connections. NZ Heavy Engineering Research Association (HERA). www.steel.org.au/resources/elibrary/library/eccentric-cleats-in-compression-and-columns-in-moment-resisting-connections

NZ Heavy Engineering Research Association (HERA). (2003, April/May). Design and Construction Bulletin No. 73: Restraint Issues Relating to Portal Frame Spline Beams. files.engineering.com/download.aspx?folder=c98c935e-1a5e-4639-963c-65b7d3560eae&file=DCB_73.pdf

NZ Heavy Engineering Research Association. (n.d.). Design and Construction Bulletin No. 75: Design of Portal Frames with Limited Restraint at the Knees.

Ministry of Business, Innovation and Employment

Practice notes

Ministry of Business, Innovation & Employment. (2005). Practice Advisory 1: Bend the Bar But Not the Rules. www.building.govt.nz/building-code-compliance/b-stability/b1-structure/practice-advisory-1

Ministry of Business, Innovation & Employment. (2005). Practice Advisory 2: Pay Attention to the Basics – Structural Concepts and Load Paths. www.building.govt.nz/building-code-compliance/b-stability/b1-structure/practice- advisory-2

Ministry of Business, Innovation & Employment. (2005). Practice Advisory 3: Beware of Limitations – Cold-Worked Wire Mesh. www.building.govt.nz/building-code-compliance/b-stability/b1-structure/practice-advisory-3

Ministry of Business, Innovation & Employment. (2005). Practice Advisory 4: Do Sweat the 'Small' Stuff – Connection Design and Detailing. www.building.govt.nz/building-code-compliance/b-stability/b1-structure/practice-advisory-4

Ministry of Business, Innovation & Employment. (2010). Practice Advisory 12: Unstiffened Eccentric Cleat Connections in Compression. www.building.govt.nz/building-code-compliance/b-stability/b1-structure/practice-advisory-12

Determinations

Ministry of Business, Innovation & Employment. (2013). Determination 2013/057: Regarding the Refusal; to Issue a Building Consent and he Code-Compliance of Precast Wall Panels to be Fixed on a Proposed Warehouse Building at 6 Edwin Feist Place, Solway, Masterton. www.building.govt.nz/assets/Uploads/resolving-problems/determinations/2013/2013-057.pdf

Poole, R. (2005, August). Report to Department of Building and Housing Review of Design and Construction of Slender Precast Concrete Walls. Ministry of Business, Innovation & Employment. www.mbie.govt.nz/dmsdocument/68-concrete-walls-report-pdf

Steel Construction New Zealand

Cowie, K., & Fussel, A. (2009, December 22). MEM 1001 and MEM 2002 Welded I Sections Seismic Category Classifications. Steel Construction New Zealand Inc. www.scnz.org/wp-content/uploads/2020/12/MEM1002.pdf

Cowie, K. (2009, August 26). CON1001 Momentum End Plate Column Side. Steel Construction New Zealand Inc. www.scnz.org/wp-content/uploads/2020/12/CON1001.pdf

Structural Engineering Society of New Zealand

Hughes, G. (2016). Some Aspects of the Design of Face Loaded Slender Precast Concrete Wall Panels (SPCWPs). Structural Engineering Society New Zealand Journal, Vol. 29(2), 26–27.

Hogan, L. S., Henry, R. S., & Ingham, J. M. (2018). Performance of Panel-To-Foundation Connections in Low-Rise Precast Concrete Buildings. Structural Engineering Society New Zealand Journal, 31(1), 26–36.

Grant, M., & Lanser, S. (2018). "Adopt a Ductility" for Steel Portal Frame Structures. Structural Engineering Society New Zealand Journal. 31(1), 38–45.

Structural Engineering Society New Zealand and Ministry of Business, Innovation & Employment Joint Working

Group. (2019). Design and Remediation of Low-Rise Industrial/Commercial Buildings. Structural Engineering Society New Zealand Journal. 32(1), 15–19.

The New Zealand Concrete Industry Conference

Allan, B.F., Chen, S.K., Henry, R.S., & Ingham, J.M. (2012). Experimental Testing of Precast Concrete Panel Connections. The New Zealand Concrete Industry Conference. www.researchgate.net/profile/Jason-Ingham-2/publication/259312445_Experimental_testing_of_precast_concrete_panel_connections/links/53cea87c0cf2fd75bc5829ee/Experimental-testing-of-precast-concrete-panel-connections.pdf

Burley, J., Faitotoa, T.,Seifi, P., Henry, R.S., & Ingham, J.M. (2014). Out-Of-Plane Behaviour of Connections Between Precast Concrete Panels and their Foundations. The New Zealand Concrete Industry Conference. www.researchgate.net/profile/Jason-Ingham-2/publication/286459556_Out-of-plane_behaviour_of_connections_between_precast_concrete_panels_and_their_foundations/links/566b438c08ae1a797e39ea42/Out-of-plane-behaviour-of-connections-between-precast-concrete-panels-and-their-foundations.pdf

Burridge, B.M., Casey, M.P., Raby, M.L., Wright, H.D., Hogan, L., Henry, R.S., & Ingham, J.M. (2015). Improved Detailing of Precast Concrete Panel to Foundation Connections to Withstand Out-Of-Plane Earthquake Loads. The New Zealand Concrete Industry Conference. www.researchgate.net/profile/Jason-Ingham-2/publication/286459377_Improved_detailing_of_precast_concrete_panel_to_foundation_connections_to_withstand_out-of-plane_earthquake_loads/links/566b400d08ae1a797e39e7bf/Improved-detailing-of-precast-concrete-panel-to-foundation-connections-to-withstand-out-of-plane-earthquake-loads.pdf

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