Design of Modular Process Plant Buildings

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Abstract

The design and construction of modular buildings for process plants involves special loading conditions not covered by Australian Standards, and requires the use of advanced structural analysis tools and techniques. This is illustrated by the case study discussed in this blog.

A major element of the Port Pirie Transformation Project was the new Furnace Building (Figure 1). Built to house the new Top Submerged Lance (TSL) Furnace and Waste Heat Boiler, the building was constructed and fitted out in China, and shipped to Port Pirie in modules for final erection.

The completed building is 75m high on a 30m x 30m footprint, and comprises:

- 4000t structural steel (including 500t of temporary transport steel).
- 2000t of mechanical and process equipment.
- 9 major modules plus interconnecting flat-pack floor panels.
- Modular exterior cladding panels.

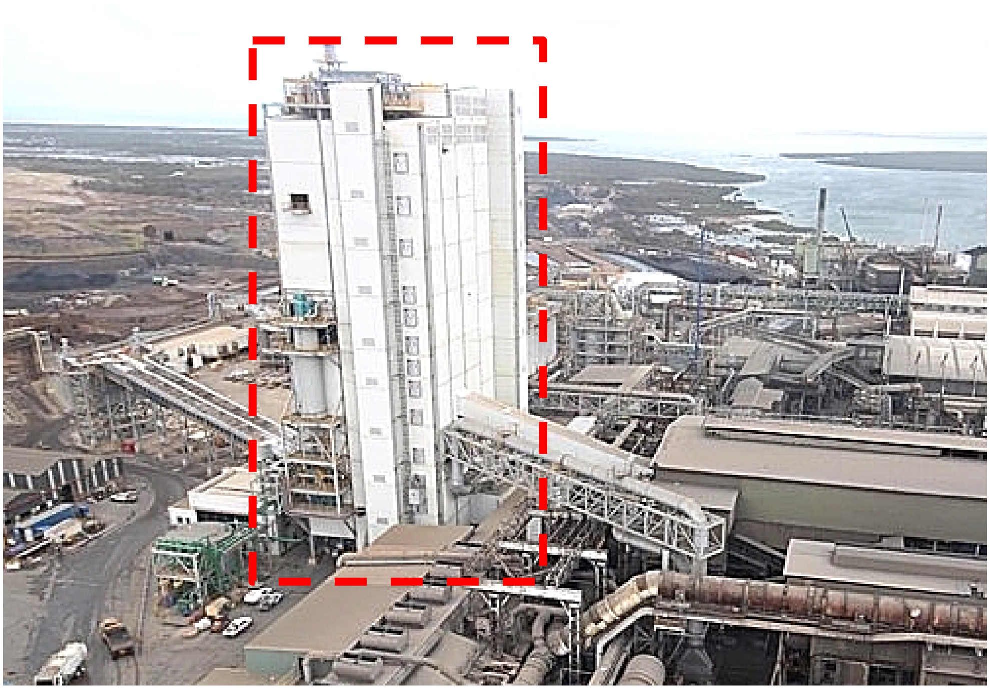


Figure 1: Furnace Building

1 Construction Strategy

1.1 Off-Shore Fabrication and Fit-Out

The furnace building modules were constructed in a module yard in China (*Figure 2*), with each module fitted out with mechanical equipment, process piping, and electrical equipment. This strategy moved a major portion of the construction effort off site, remote from the constraints imposed by the smelter operations. Equipment installed in the module yard included:

- 200 tonne Waste Heat Boiler, delivered in six (6) major sub-assemblies across three (3) building modules.
- Boiler ancillary equipment including feed water pumps, circulation pumps, feed water tank and, steam drum.
- Coal injection equipment, including coal silo and pneumatic powder handling equipment.

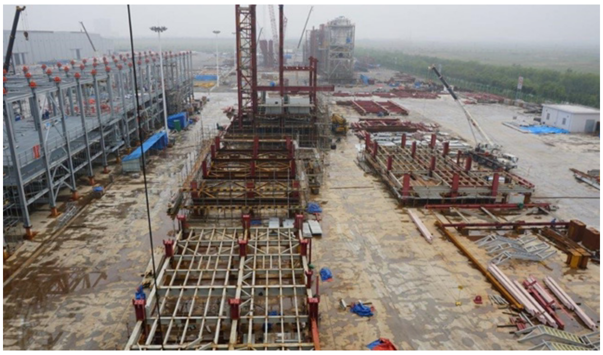


Figure 2: Module Yard

1.2 Site Constraints

The Port Pirie smelter is a crowded brown-field site, with infrastructure buildings and operational process plant surrounding the site for the TSL building. The logistics of unloading modules at the smelter wharf and transporting them through the existing plant to the building site imposed strict design limits for the module dimensions and mass (*Figure 3*).

Figure 3: Moving Modules on Site

2 Loading Conditions

2.1 Design Actions

Australian design standards are written primarily for the requirements of designing conventional buildings for human occupation. Design loads for buildings are typically limited to a small number of simply defined action types (*Table 1*). The complexities of process plant design requires that these load types be expanded to separate dead loads and imposed loads into sub-actions (*Table 2*).

For transport and erection of a modular building, additional actions must be considered. Design actions for transporting and handling the building modules are discussed in Section 2.2 to 2.4.

Table 1: AS1170 Design Actions

Action	Description
G	Dead load
Q	Live load
W	Wind action
E	Seismic action

Table 2: Design Actions for TSL Furnace Building

Load Group	Action	Description
Dead Loads	Gst	Structure Dead Load
	Geq	Equipment Dead Load
	Gpip	Piping Dead Load
	Gsv	Services Dead Load
Live Loads	Qfl	Floor Live Load
	Qeq op	Equipment Operating Contents
	Qeq fl	Equipment Flooded Contents
	Qp op	Piping Operating Contents
	Qp fl	Piping Flooded Contents
	Qp th	Piping Thermal Loads
	Qlt	Lance Trolley Loads
	Qm	Mudgun Operating Load
	Qli	Lance Impact Load
		Crane Loads
		Monorail Loads
Wind and Earthquake	W	Wind action
	Eq	Seismic action
Module Handling	Ts	Sea Transport loads
	Tr	Road Transport loads
	Tl	Lifting loads

2.2 Sea Transport

The furnace building modules were transported from China to Australia on heavy lift ships (*Figure 4*). Wind and wave actions on the ship impose large inertia loads on the modules (*Table 3*). These loads often governed the design of columns and bracing, particularly for modules located higher in the building. Additional temporary bracing was usually necessary to resist the lateral inertia loads.

To secure the modules for sea transport, they must be securely lashed to the deck of the ship (*Figure 5*).

Table 3: Design Actions for Sea Transport

Action	Acceleration	Minimum at C of G
Lateral acceleration due to roll and sway of the ship	(0.50+0.025 h) g	0.75 g
Longitudinal acceleration due to pitch and surge of the ship	(0.15+0.005 h) g	0.25 g
Vertical acceleration due to roll and sway of the ship	(0.35+0.020 h) g	0.40 g

h = height of module Centre of Gravity above the deck of the ship

Figure 4: Heavy Lift Ship

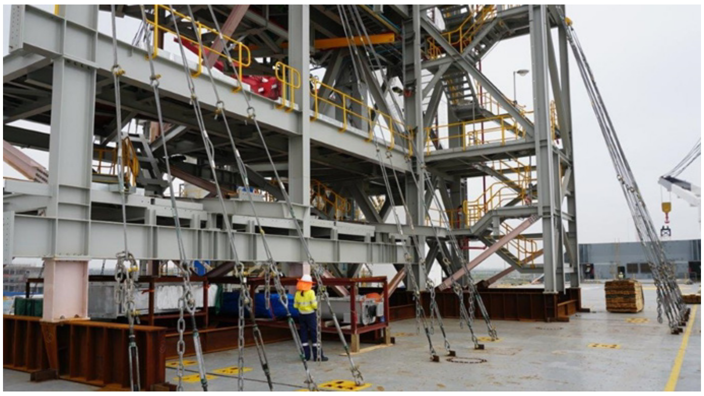


Figure 5: Module Lashed to Ship Deck

2.3 Self-Propelled Modular Transporters

The modules were transported on land using Self Propelled Modular Transporters (SPMTs). Each module was provided with a temporary grillage to support the module on the SPMTs (*Figure 6*). SPMTs are used around the world for moving large and heavy loads. By ganging transporter modules together in the required configuration, modules of almost any size may be handled.

The design actions imposed during SPMT transport are similar to those described for sea transport. However, the slow, controlled movement of the SPMT group imposes much smaller design accelerations (*Table 4*).

Table 4: SPMT Loads

Action	Acceleration
Lateral acceleration	0.08 g
Longitudinal acceleration	0.21 g
Vertical acceleration	0.05 g

Figure 6: SPMT

2.4 Lifting

The furnace building modules were designed for a four point crane lift for loading/unloading from the ship (*Figure 7*) and installing in the building (*Figure 8*). The basis of design for lifting was as follows:

- Four point lift, with vertical slings attached to nominated lifting points on the modules.
- Standard 200 tonne WLL pad eyes bolted to the nominated lifting points.
- Slings and spreader bars arranged to distribute and share the load between the nominated lifting points.

Additional temporary bracing was usually necessary to transfer the module loads to the lifting points.

Figure 7: Module Lifting – Ship to Shore

Figure 8: Module Lifting – Installing in Building

2.5 Equipment and Process

The contents of the process equipment is a large proportion of the live loads imposed on the TSL furnace building structure. These loads were assessed and applied to allow for the range of operating scenarios that may occur during the life of the plant. Imposed loads for the process contents for the equipment and piping were assessed as follows:

- Equipment and piping filled to *maximum operating level* with process contents at *maximum operating density* (maximum operating condition).
- Equipment and piping filled to *maximum possible level* with process contents at *maximum design density* (flooded or blocked condition).
- Equipment and piping filled with water (hydrostatic testing).

2.6 Live Loads

An area live load of 5.0 kPa usually provides adequate allowance for personnel access, material laydown, and process spillage on the operating floors of a process plant. To cater for the special maintenance requirements of the TSL furnace, floor live loads of up to 25 kPa were applied in specifically nominated areas of the furnace building.

2.7 Wind Loads

Wind loads, including allowance for dynamic effects, were applied to the TSL furnace building in accordance with AS1170.2. Different design wind speeds were used for the various phases of the building life (*Table 5*). Wind loads for SPMT transport and sea transport were applied in conjunction with the inertia loads discussed in Section 2.2, 2.3.

Table 5: Design Wind Speeds (ULS)

Construction Stage	Design wind speed (m/s)
Module SPMT Transport	20
Module Sea Transport	35
Completed Building	45

2.8 Seismic

The TSL building is supported on deep piles (~25m deep), bored into deep soft clays. The deep soft soils (Sub-soil classification D_e) in combination with a relatively high site hazard factor (Z = 0.1) resulted in relatively high seismic loads by Australian standards. However, for overall design of the building, wind loads exceeded the seismic loads. For local support of equipment within the building, the Sea Transport Loads discussed in Section 2.2 far exceeded the seismic loads.

3 Analysis

3.1 One Model Approach

Analysis of the building modules for the different structural configurations, boundary conditions, and transport loading scenarios would typically necessitate breaking up the building analysis model into separate models for each module, with individual models modified to suit the shipping and transport loading requirements. This approach is both time consuming and a potential source of design error. With suitable software, the analysis and design of the individual modules, and of the completed building, can all be performed within the one model.

3.2 Software

Analysis of the building was performed using Strand7 software (*Figure 9*). Strand7 provides a number of advanced modelling features which were particularly useful for the analysis of the furnace building:

- Definition and analysis of multiple different boundary conditions (freedom cases).
- Definitions of analysis stages, with activation or suppression of groups of element for each stage.
- Ability to graphically copy and paste models seamlessly into other models.

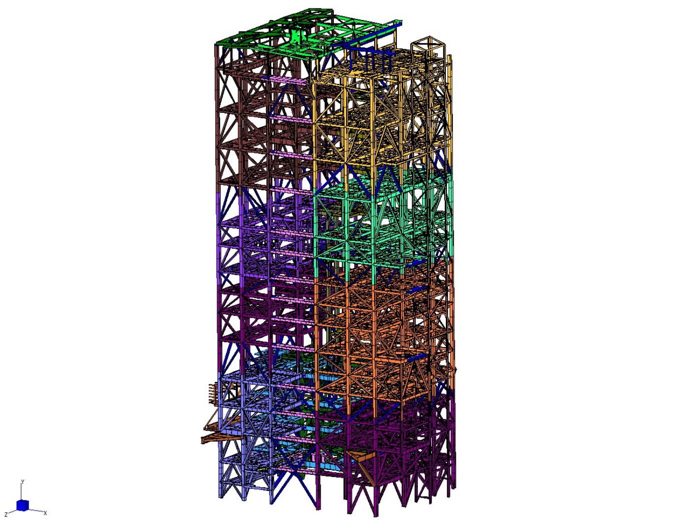


Figure 9: Analysis Model for TSL Furnace Building

Design of the steel framing members was completed using BCDsteel software. BCDsteel accesses the Strand7 analysis results to perform code checks in accordance with AS4100, and provides graphical output of member capacity utilisation ratios (*Figure 10*).

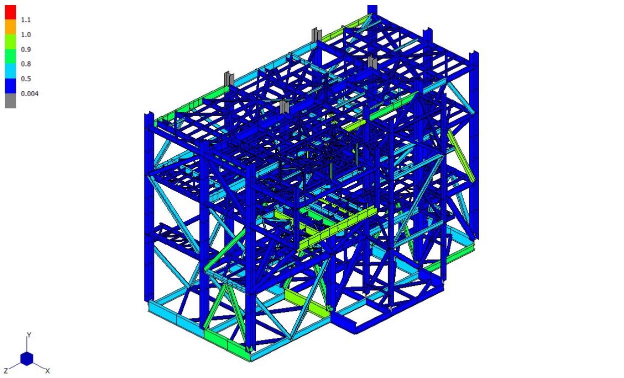


Figure 10: Member Capacity Utilisation Ratios for a Module

3.3 Modelling Strategy

The magnitude of the design task required that the workload be shared amongst a team of structural engineers. To ensure efficient coordination of the team effort, the following modelling strategy was implemented:

1. Master model template created, incorporating:
    a) Standardised section library.
    b) Primary framing to define building grids, floor levels, columns, and module splits.
    c) Primary load cases for all loads listed in Table 2.
    d) Element groups, analysis stages, load combinations, and freedom cases defined for all design scenarios, including:
        i) Completed building.
        ii) Module sea transport.
        iii) Module SPMT transport.
        iv) Module crane lifting.
2. Detailed designs for individual building floors were developed by individual engineers using the master model template, and then pasted into the master model.
3. Detailed designs for transport bracing and grillages for individual modules were developed by individual engineers, and then pasted into the master model.
4. Column and bracing design was developed in the master model.
5. Final code checks for all design scenarios was performed in the master model.
6. Any subsequent design changes were implemented only in the master model (design development sub-models were set aside once pasted into the master model).

3.4 Load Application

The transporting and handling the modules involved inertia loads in various directions. By using non-structural masses for all structure and equipment dead loads, in conjunction with relevant accelerations, the application of these inertia loads was greatly simplified.

The use of non-structural masses also enabled the mass and centre of gravity of the modules to be directly extracted from the model (refer Section 3.7)

3.5 Analysis Stages

Analysis stages were defined to enable the building and modules to be analysed using the one model. For each stage, only the relevant parts of the model, together with the appropriate freedom case, were activated. A typical stage, used for analysis of a module for sea transport, is illustrated in Figure 11. The following model element groups are activated for this stage:

- Module permanent framing (purple).
- SPMT transport grillage and temporary bracing (green).
- Sea transport and lifting temporary bracing (red).
- Lashing for tying module down to ship deck (yellow).

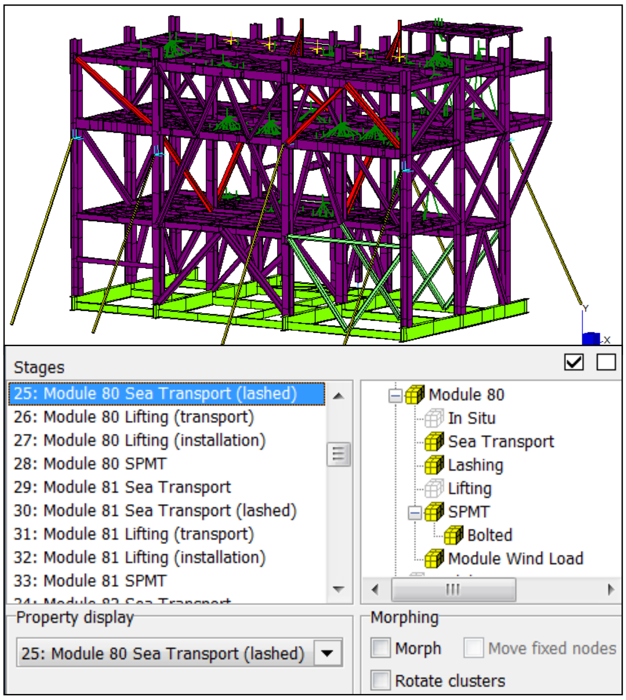


Figure 11: Analysis Stage –Sea Transport of a Module

The use of stages also simplified the application of moving loads to the building. For each moving load, a single primary load case was defined, with the loads attached to the model via links. Stages were defined to activate or suppress the links for the different load positions.

Analysis of the furnace building for all scenarios, including transport, lifting, operating loads, equipment moving loads, wind loads, and seismic loads, required:

- 94 separate analysis stages.
- 1,171 load combinations.

3.6 Load Factors

The load combinations defined in AS1170.0 do not adequately cover the complexities of the loading scenarios applicable to process plant design. Imposed loads for peak operating and extreme operating conditions in a process plant have a lower probability of exceedance than the normal operating loads. For example, it is virtually impossible to exceed a flooded process vessel load that is based on upper bound values for both filled volume and contents density. For design of the furnace building, Ultimate Limit State (ULS) load factors were applied based on the load combination groups listed in *Table 3.1* below.

Table 3.1 Load Combination Groups

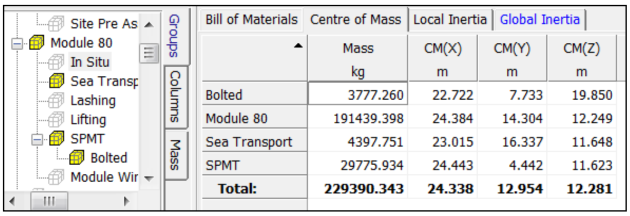
Load Group	Imposed Loads	Load Factor for Imposed Loads
Normal Operating	Floor Live Load Operating Process Material Load Worst case combination of at rest, running, and/or starting belt tensions Equipment dynamic loads Operating wind load	1.5
Peak Operating	Floor Live Load Blocked/Flooded Process Material Load Worst case combination of at rest, running, and/or starting belt tensions Equipment dynamic loads Operating wind load	1.2
Extreme Operating	Floor Live Load Blocked/Flooded Process Material Load Stall tension for any one conveyor in conjunction with running belt tensions for all other conveyors Equipment dynamic loads Operating wind load	1.1

3.7 Weight Control

The logistics of each phase of construction, from module yard to final erection, require careful planning to ensure that the rigging and handling of modules is carried out in a safe and stable manner at all times. It is therefore essential that the mass and centre gravity of each module is accurately determined.

Weight control for the furnace building modules was implemented as follows:

- A register of all mechanical and process equipment in the building was maintained, to record equipment name and number, equipment loads, floor level and module in which the equipment was located, vendor drawing numbers, and equipment data status.
- The equipment register was checked and updated as each issue of vendor data was received.
- The equipment loads in the analysis model were cross checked against the equipment register and against the vendor data.
- Mass and Centre of Gravity for each module were reported directly from the analysis model (*Figure 12*).



	Mass kg	CM(X) m	CM(Y) m	CM(Z) m
Bolted	3777.260	22.722	7.733	19.850
Module 80	191439.398	24.384	14.304	12.249
Sea Transport	4397.751	23.015	16.337	11.648
SPMT	29775.934	24.443	4.442	11.623
Total:	**229390.343**	**24.338**	**12.954**	**12.281**

Figure 12: Module Mass and Centre of Gravity

4 Conclusions

The structural design of modular buildings for process plant requires the consideration of complex loading scenarios for the construction and operation of the plant. For the TSL furnace building, this challenge was met by:

- Application of well-defined project design criteria.
- Use of structural analysis software with advanced modelling features.
- Leveraging the software capabilities through application of well-planned modelling strategies.

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