Transportation Considerations in Module Design

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INTRODUCTION

Shipping logistics and transportation form integral parts of modularization design and are influenced by the geographical location of the facility, the type of modularization, and the location of the module fabrication yard.

In addition to loads from on-site conditions, modules are required to be designed for the fabrication, transportation and installation loads. Modules may need to be designed for sea and land transportation loads, staging loads, and maximum axel load limitations. In addition, the stability at various stages of construction becomes an integral part of the structural design. The module supporting structure is typically much heavier than a corresponding site-erected, stick-built supporting structure. A modularized supporting structure could contribute as much as fifty percent of the total weight of the module.

Shipping logistics are not finalized until late in a project. It is difficult to develop an economical module design approach considering sea and land transportation loads when the transportation route and climatic conditions are not well defined in the early engineering phase. Land transportation becomes specially challenging when there are existing bridges and roadways along the route. These existing bridges and roadways are in many cases deigned to cater to regular vehicular traffic and are not suitable of modular heavy haul axle loads. The goal is to minimize any impact on existing bridges, roadways and day-to-day traffic.

This paper outlines the various transportation considerations in module designs and their impact on the structural configuration of the module. It also provides a few recommendations for safe and economical structural design of modules for transportation loads.
LAND TRANSPORTATION

Land transportation planning is often done when a heavy or oversize item is nearly completely fabricated. However, modularization presents an opportunity to coordinate and optimize land transportation from the feasibility stage. There are a multitude of land transportation methods such as rail, over the road transport, skidding, rollers; however, for purposes of this paper, discussion will be limited to land transportation of modules with self-propelled modular transporter (SPMT) and will focus on how land transportation relates to module design.

Designing a suitable transport configuration entails much more than simply comparing the weight of the module to the payload capacity of an SPMT. The transport configuration must be suitable for the weight, center of gravity, and support conditions of the module as well as match marine transport method, haul route details (such as bridges or overhead obstructions), and site details such as staging, heavy haul route constraints within the site, final setting method etc.

An optimized module design incorporates transportation study early in the design process to establish a dialog between land transportation engineer and module design engineer. During feasibility study, transport configurations are developed for envelope dimensions (as required by route and site restrictions), approximate weights, assumed center of gravities, and assumed support module support points. As the project progresses, the transport configuration is refined to meet the specifications of the module. The module design engineer will incorporate the latest transport configuration to analyze the module and work with the transport engineer to find an adequate transport configuration.

Examples of challenges that can arise during design include offset of center of gravities and limitations on imposed axle loadings. Offsets in center of gravities and its consequent effects on stability angle can be addressed by repositioning the SPMT’s under the module, adjusting the hydraulic suspension, or by using additional axles. Imposed axle load limitations often require the use of more axles; however, if the SPMT beam overhangs the module excessively then use of temporary load spreading mats or temporary outriggers can be required to adequately distribute the module weight, see Figure 8.

Modules can be installed by a variety of methods to accommodate the final position of the module such as SPMT install, jacking up/down, crane setting, and specialty methods. For SPMT install of modules, the built in hydraulic suspension of the trailer is used to install the module directly onto permanent foundations. For SPMT install, modules are often designed to be permanently supported either directly on girders or columns. Modules permanently supported on girders benefit from foundations designed to match the 1.5m [5ft] SPMT mid stroke deck elevation as shown in Figure 1.
Similarly, modules with permanent support columns protruding lower than the SPMT deck also benefit from support columns of 1.5m [5ft] matching the SPMT mid stroke deck elevation. Moreover, column base plate details play an important part of an efficient direct SPMT module install. One successful approach is the use of flush base plates that bear onto a steel cap plate that is later welded together as shown in Figure 2. This method allows for a shorter installation time compared to bolted base plate connections because the base plate does not foul on bolts protruding from the foundation.
The benefits of engaging transportation planning are:

- Avoiding project delays because route and site restriction are known upfront prior heavy or oversize equipment arriving on site.
- Optimization of module size and weight, which streamlines the logistics process.
- Helps in early transportation permitting work with local authorities especially when modification of overhead power lines, street signs and traffic lights is needed to accommodate the module envelope.

The improved module design fostered by the partnership of an experienced land transportation company will ensure that the module can safely reach its destination and will do so with improved efficiency because even smaller details such as base plate design and support structure will be optimized.
MARINE TRANSPORTATION CONSIDERATIONS

Although marine shipping logistics are not finalized until late in the design phase of a project, it is imperative to consider several aspects of marine transportation early in design. The design spiral, a paradigm common in naval architecture, lends itself well to modularization design. In this design approach early estimates are repetitively refined as the design is iterated to converge, or spiral in, towards the final solution.

Shipping logistics and transportation form integral parts of modularized design and are influenced by the geographical location of the facility, the type of modularization, and the location of the module fabrication yard. The design basis for a successful modularization program should include best estimates of the anticipated shipping route and schedule. Conceptual estimates of module dimensions, weight, and center of gravity are also necessary to guide marine transportation planning. Considerations related to shipping route, transport vessel capacity and availability, metocean conditions, and port facilities can limit module size and/or inform selection of module breaks. Waiting until module design is complete to plan marine transportation can lead to uneconomic shipping solutions, transportation delays, and module design rework. It is critical to develop the module “design envelope” for the operating area and then use these limitations to design the modules. Many factors associated with operating areas cannot be changed, but module design usually can be modified.

Several design considerations related to marine transportation play a pivotal role in successful modularization design. These considerations include transport vessel stability, transport vessel structural integrity, anticipated environmental conditions and resulting module loads along the shipping route, and module offloading. The basics requirements for marine transportation are well covered by published regulatory guide. For example, “Guidelines for Marine Transportations,” by GL-Noble Denton, covers topics such as vessel stability, motions, strength, towing vessel selection, and mooring.

The discussion herein is limited to aspects of the marine transportation plan that can directly impact module design.

Stability

The stability of available transport vessels can govern the maximum allowable weight and vertical center of gravity of the modules. Ballasting requirements to maintain trim during module roll-off commonly govern the offloading cycle time, and therefore, impact operability.
Structural Integrity

The required securing systems for the module transport and the module weight distribution need to be evaluated for the transport barge. Deck cargo barges are fairly robust; however, there may be structural limitations related to either deck strength or global bending of the hull girder. Alternating deformations of the hull girder impose cyclic loading on the modules in a seaway. An evaluation of the structure loads and material limits must be performed.

The sea-fastenings for modules and other large payloads typically consist of a series of shear stops and shear plates welded to both the barge deck and module. The seafastening system is designed to support the forces imposed by longitudinal and transverse accelerations. Additional clips may be required to restrain uplift if calculations indicate that overturning is possible.

Figures 3 through 6 illustrate a typical seafastening arrangement for a dry-towed barge. Figure 3 provides an overview of the example loadout, a series of three smaller barges stacked on the deck. The transverse shear stops, painted yellow, are clearly visible along the starboard side. Figures 4 through 6 provide further details.

Module transportation often requires similar seafastening details; however, it also offers the opportunity to design a tie down system for efficient connection to the deck. A common approach uses a number of longitudinal wide flange beams to support the module footprint and span major barge deck structure. Figure 7 shows this arrangement disconnected and ready for offloading.

Figure 3 – Sea-fastening example.
Figure 4 – Typical sea-fastening shear stop.

Figure 5 – Typical shear stop (transverse restraint).

Figure 6 – Typical shear plate detail (longitudinal restraint)
Early estimates of vessel motion-induced accelerations can be made with parametric formulae published by DNV, requiring route, barge length, beam, draft, block coefficient, and module weight and center of gravity as input. Hydrodynamic analysis can provide refined design accelerations as the project develops and details of the marine transportation plans mature.

![Figure 7 – Module supports for sea-fastening](image)

**Environmental Conditions & Loads**

Towing loads are a function of transport vessel size, module projected area, wind speed squared, and significant wave height squared. Therefore, determination of module size must consider the capacity of available towing vessels and the anticipated climatological conditions along the shipping route.

The loads imposed on modules during transit are driven again by transport vessel size, module weight and vertical center of gravity, and the metocean conditions expected. In general a lower center of gravity will result in lower motion induced loading on the module structure and sea-fastenings during transport. In fatigue sensitive modules, the load cycles accumulated during the delivery voyage can consume a significant portion of the modules fatigue life. Route selection, weather routing, tow speed, and location of fatigue sensitive module details can mitigate these effects.
Wave impact loads on module structure are possible for large modules which overhang the transport vessel. Overhanging loads can lead to uplift on the seafastenings if roll motion submerges portions of the module.

**Module Offloading**

In general the module fabrication is performed at yards with suitable facilities for loading modules aboard transportation vessels. However, module offloading is often required in remote areas lacking infrastructure. In such cases, offloading facility design should begin in parallel with module design and marine transportation planning. Alternatively, offloading over the beach can be considered if conditions permit and the risk of damaging the transport barge is acceptable.

Site conditions such as water depth and exposure can limit module size. Practical limits of standard mooring hardware for new offloading facilities or the actual mooring hardware available at pre-existing offloading facilities can also limit module size or result in weather restricted operations. Module size should be carefully selected to balance the needs of an economic module design with the required module transportation throughput. The fewest number of large modules is not always the optimum solution for the overall project.

**IMPACT OF TRANSPORTATION LOGISTICS ON STRUCTURAL MODULAR DESIGN**

Several key parameters such as module envelope and maximum module weight are directly impacted by the outcome of the transportation and logistics considerations. These parameters, in turn, impact the selection of type and level of modularization of the plant. The limiting weight and size of the module envelope is also dependent on the design of the roads and bridges along the land transportation route.

The structural engineering considers the additional loading and design considerations due to the land and sea transportation. To maintain a cost effective design it is important that experienced structural engineers design the major structures using industry practices and good engineering judgment to differentiate between temporary and permanent loading and to use temporary members for design of transportation conditions. In module design, space is very important thus the engineer should also ensure that members are not provided if not required by on site condition load combinations. At the same time it is also important to reduce the field work for removing temporary members and connections.
It is important that the structural engineer considers all the structural safety and stability of the structure during assembly at the fabrication yards. This typically involves designing the structural members based on different support/lifting locations and conditions.

The Structural Engineer should work very closely with the land transportation engineering so as to clearly understand the limitation and load distribution mechanism of the hydraulically operated, self propelled module transporters (SPMT’s) used to transport the module on land. For stability of the structure during transportation the center of gravity of the structure should match the center of gravity of the reaction of the SPMT beam. If the required length of the SPMT beam is very far beyond the end of the structure, outriggers are required to prevent the caving effect of the SPMT beam. Outriggers and other supports add considerable steel weight with a cost and schedule impact for engineering, fabrication installation, and removal. There is some room for optimization by working with the SPMT engineers to slightly redistribute the pressure on the SPMT beam to match the center of gravity of the module. Other factors such as location of stowage loads and location of the power packs of the SPMT could help in redistribution of the reaction from the SPMT beam and avoid the requirement of outriggers. The outriggers and temporary bracing are provided for transportation and have to be removed before installation thereby adding considerable engineering, fabrication and installation cost and schedule.

There could be different types of land transportation and the loads may vary. As an example the SPMT arrangement from the fabricator to the shore line for loading the barge may be different than that from the off loading pier to the site location and/or the install location. As there may be different loading conditions in each of the cases the engineers have to ensure that the structure is safe and stable during each of these conditions.

The Structural Engineer should also verify the support locations and conditions during the weighing of the module at the fabrication yard. The structural
engineer also designs temporary support for piping and other parts of the equipment if it cannot take the additional forces during transportation.

The vessel’s motion such as such as heave, roll, pitch and yaw cause sea forces on the structures. These Sea forces have a major impact on the design of the Structures as the hogging and sagging forces in head sea conditions during transport add the dominant forces impacting the module structural members. These forces are dependent on location, orientation and placement of the module on barge. A detail study of this information could help in optimizing the structure. The Structural engineer is also responsible to tie the modules to the vessel deck.

![Figure 9-Vessel Motion Inducing Sea Forces](image)

Engineering typically maintains a record of the Center of Gravity and the module weight throughout the project and this information is shared with both the land and sea transporter. It is important to use high strength steel so as to reduce the weight of the structures. The weight savings typically offset the additional cost of steel. Based on the logistical study there may be Civil engineering work of upgrading the existing infra-structure, building temporary piers, and verifying and upgrading existing bridges.

**CONCLUSION:**

A significant amount of planning, scheduling, communication, and experience is necessary to successfully transport modules from a module fabrication yard to a job site. This effort typically includes multiple parties with expertise in transportation, logistics, rigging, naval architecture, structural engineering, and project management. Integrating land and marine transportation planning with module design early in the modularization program gives module designers a holistic view and helps inform their design decisions for optimum project outcome.