Loading of steel coils

"To determine how many steel coils to carry in one cargo hold, multiply the tank top area by the allowable tank top load." Is this the best assumption to deal with steel coil loading? This article intends to answer this question by explaining the special features of steel coil loads and how the hull structure responds accordingly.

The question has been asked many times - "Can the cargo hold be loaded with steel coils up to the weight calculated by multiplying the tank top area (m2) by the allowable tank top load (ton/m2)?" Sometimes this question is answered in the affirmative and a vessel is loaded with steel coils accordingly. However, this is not the best assumption for the vessel.

DNV recently issued "Casualty information No.5 -10 June 2010". This information reveals damage to a vessel's inner bottom caused by steel coils. After the cargo was discharged, the vessel was found to have indents on its inner bottom plate. Below the cargo holds, the longitudinals and floors were also damaged (Figure 1).

Steel coil loads into the hull structure

Steel coils are rolls of thin steel plates with variable lengths and diameters. A typical dimension for design purposes is 1.5m in diameter, 1.5m in length and 15 tons in weight. Steel coils are stowed in the cargo holds with their axis in the ship's longitudinal direction. In between the coils and inner bottom plating, wood dunnages are arranged in the ship's transverse direction. The steel coil load will then be transferred through dunnages into the inner bottom plating, longitudinals, double bottom girders and hull girder structure in sequence.

Special features of steel coil loads

Typically, three dunnages are arranged for each row of steel coil (Figure 2). Dunnages are pine planks with a normal cross section of 100-150mm in width and 30mm in thickness. They are arranged in order to prevent steel-to-steel contact between the inner bottom plating and steel coils and to prevent abrasion in between. Generally, the quality of the dunnages is not controlled. Dunnages are also much less stiff than tank top structures, so that the load transferred through their bending into longitudinals is negligible. Therefore none of the Classification Rules contains a requirement about the properties of dunnages and the dunnages' bending capacity is ignored.

Dunnages are soft compared to steel coils and will deform in the area where they come into contact with coils. The load through the dunnages to the inner bottom plating will thus be a kind of rectangular shape with a small area (Figures 3 & 4), equal to the width of the dunnages multiplied by the contact distance (which depends on the steel coil diameter, but may be assumed to be 30% of the longitudinal spacing). When many dunnages are arranged for one steel coil, in extreme conditions as a wood sheet, rectangular loads from the coil will assemble a rectangular line load in a longitudinal direction. However, in a transverse direction, due to the coil’s diameter, there will still be a large spacing between these line loads. Therefore, the steel coil load is not a uniform pressure load on the entire inner bottom.

The rectangular load is a fundamental parameter for checking the local structure strength. As illustrated in Figure 3, ignoring the friction between steel coils, it is assumed that gravity loads and
inertia loads due to vertical acceleration from the upper tier of coils are transferred equally to the lower tier. The same principle applies to calculating rectangular loads. Standard steel coil loading conditions included in the loading manual are normally based on steel coils with the same weight and dimensions. When coils are different, rectangular loads can be calculated in the same reasoning and compared with loads from the standard condition.

Due to the special features of steel coil loads, the local structure strength of the inner bottom plating and longitudinals must be specially checked. However, the responses of the double bottom girder system and hull girder are not different. This will be discussed below.

**Local structure**

Typically, the steel coil’s diameter does not match the longitudinal spacing, meaning that rectangular loads may act on the inner bottom plating in the middle of two longitudinals (Figure 3). This is the extreme condition against which the strength of the inner bottom plating must be checked.

The Rule formula for plating thickness is based on the plastic collapse of a plate panel with fixed boundaries. The simple example below illustrates how load distribution affects the required plating thickness. The example is based on steel coils of 1.5m in diameter (Ds). The longitudinal spacing (s) is 0.8m (typical for Handy size bulk carriers). Many dunnages are arranged for each row of coils so that there is a rectangular line load (QL) on the inner bottom. As sketched in Figure 5, in Case A (not realistic as discussed), QL is further distributed in a transverse direction along Ds, resulting in the same uniform pressure from dividing the total steel coil load by the inner bottom area. In Case B (close to reality), QL is distributed in 0.3s transversely as assumed for a rectangular load. In Case C, QL is not distributed transversely as an extreme condition. The plating thickness requirement compared to Case A is shown in Table 1.

Similar to the discussion for plating, rectangular loads may be acting on one longitudinal. This is the extreme condition for longitudinals. The Rule formula for the section modulus and shear area of longitudinals is based on an elastic beam with both ends fixed. In reality, the bending of the inner bottom plating will transfer some loads (about 10% depending on spacing and plating thickness) to adjacent longitudinals. Since the portion is very limited, all loads are assumed to remain on one longitudinal and are simplified as point forces, while adjacent longitudinals take almost no loads. This assumption gives an accurate enough result compared to those from fine mesh finite element analysis.

Referring to the example for plating, the longitudinals in Case A have a uniform pressure load. For longitudinals in Case B & C, the line load is uniform. The requirement regarding the section modulus and shear area of longitudinals compared to Case A is shown in Table 1. The reason for the difference is - all the longitudinals are utilised under a uniform pressure load (Case A), while they are in reality only partly utilised under steel coil loads.

It is clear that rectangular loads from steel coils are very different from uniform pressure loads. In relation to the local strength of the inner bottom plating and longitudinals, the special features of steel coil loads should be taken into consideration.

**Double bottom girder system**

It is not only steel coils that transfer loads onto the double bottom girder system. The overall strength of double bottom girders for each cargo hold and each two adjacent cargo holds is controlled by hold mass diagrams. These diagrams show the relationship between the cargo mass and the draught in order to control the net load. On ships with a loading computer system, these diagrams are integrated into the system and the master can easily check whether or not the planned steel coil loading condition is suitable for the strength of the cargo holds.

However, as discussed previously, some longitudinals may take more steel coil loads while adjacent longitudinals are not fully utilised. Consequently, the requirements regarding the connection area and the area where longitudinals are welded to floors may increase. The buckling of floor panels must be also checked.

**Hull girder**

In order to control the hull girder strength, the allowable bending moment and shear force must be evaluated for the planned steel coil loading condition. It should be noted that, for ships required to comply with IACS UR S17 (hull girder requirement in flooded cases), the allowable bending moment and shear force in flooded conditions must also be checked. Steel coils are high density cargo. This means there is more space for sea water if a cargo hold is flooded. When the flooded hold is in the
middle part of the ship, the sagging moment will be much larger than in a "normal" homogeneous loading condition.

**Rules for plating and longitudinals**
Due to the special features of steel coil loads, there are special Rule requirements for local structures.

The DNV Rules refer to Classification Note No. 31.1 (CN31.1), which includes an acceptable calculation method for evaluating the inner bottom plating and longitudinals under steel coil loads. The method in CN31.1 is based on the SR166 report issued by the Shipbuilding Research Association of Japan in March 1977, which is also the basis for many other classification societies' rules. The method has taken into consideration the special features of steel coil loads as discussed above.

In CSR for Bulk Carriers, Ch. 6 Sec.1 and Sec.2 include requirements for the plating and longitudinals under steel coil loads. The principle of CSR is similar to the SR166 report. However, the Rule text has been modified to fit CSR's format.

The CSR that was valid before 1 July 2009 mentioned that when the number of load points for each plate panel was more than 10 and/or the dunnage number was more than 5, the inner bottom could be considered to be loaded by a uniform distributed load. This requirement created some misunderstanding. For example, if the dunnage number was 6, the inner bottom could be considered to be loaded by a uniform pressure load, taken as the total weight of one cargo hold divided by the inner bottom area. As discussed previously, this misunderstanding did not take the special features of steel coil loads into consideration and was not safe.

In CSR Rule Change Notice No.1-3 (RCN1-3), which became effective on 1 July 2009, the original sentence is deleted to avoid this misunderstanding. RCN1-3 also revised the formula for accelerations in the steel coil loading condition and for plating thickness. As explained in annex 2 of RCN1-3, the required net plating thickness for the inner bottom and hopper tank top is similar to that of designs before CSR. However, the gross thickness requirement has been increased from 3 to 4 mm due to the corrosion addition difference between CSR and non-CSR vessels. Requirements for hopper tank top plating and longitudinals have also been modified and are more reasonable now compared to requirements for inner bottom structures.

**DNV's service in connection with the loading of steel coils**
DNV verifies the hull structure strength based on design steel coil loading conditions as part of the standard approval scope of hull structure drawings during the newbuilding stage.

For ships that are loading steel coils, DNV has a spreadsheet available to check the local strength of the inner bottom plating and longitudinals based on inputs: Length, dunnage numbers and weights of steel coils in each cargo hold provided the ships are built to DNV class. For other ships, and in cases where the steel coil combination is more complicated, DNV is available to support the verification of hull structure strength as well.

Date: 2010-08-31

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