Basic Crane Design and Stress Analysis

An Online Continuing Education Course for Engineers

Course Number: S-3032

Credit: 3 Hours / 3 PDH / 3 CPD

SECT I.2: NOMENCLATURE

As-----------------Area in Shear
C------------------Distance from neutral axis to fiber stress S, in.
Fb-----------------Allowable Bending Stress
Fbr----------------Allowable Bearing Stress
Ft-----------------Allowable Tension Stress
FTK--------------Foot-Kips
Fv----------------Allowable Shear Stress
I-------------------Moment of Inertia
Mt----------------Rotational Torque
R-----------------Radius
T-----------------Torque
Sb----------------Calculated Bending Stress
Sbr---------------Calculated Bearing Stress

$$\sigma_v, \sigma_x, \sigma_{br}, \sigma_{b---}\ Calculated\ shear, x, bearing\ or\ bending\ stress$$

May also be seen

St------------------Calculated Tension Stress
Sv----------------Calculated Shear Stress
TS---------------Tensile Strength
YS---------------Yield Strength
Z-----------------Section Modulus

SECT I1: COURSE DESCRIPTION

This course demonstrates the use of various stress analysis procedures and methods used to design cranes or other lifting components. The methods used could also be applied to other structures or lifting devices. Note that some of the problem examples in this course use simplifying assumptions to reduce the procedures to hand calculation methods. The assumptions in this course have been supported by FEA analysis, where noted. It's possible that these assumptions may not apply to all the ranges of applications or types of cranes possible. Hand calculations alone are not always recommended when simplifying assumptions are used and should be backed up by an FEA analysis and code standards (where applicable). On the other hand, FEAs alone should not be used unless supported by some hand calculations to support any boundary/support assumptions used.

The course goes through the steps required to design components fabricated from aluminum. Further design criteria for aluminum can be found in the Alum Association Standards and Alum Design Manual. This course is not meant to take the place of these standard design practices. It is a prime example of the use of these practices. Other applications may require further study of these manuals and design codes. The procedures used here could also be used for steel components, along with the AISC standards. The components in these examples are designed to somewhat conservative allowable stresses and standards.

The crane used as an example in this course is designed to SOLAS (safety of life at sea) standards, and you will see this referenced in some of the verbiage (see section 1.0). A lot of the mobile cranes you see are telescopic. Telescopic crane design may be discussed in part 2 of this course, if there is enough interest.

It is assumed that the student is somewhat familiar with design codes such as the AISC, and this should not be considered a replacement for these codes.

It is recommended that the figures be opened in a separate PDF file so that both the figures and text can be viewed side by side, as the figures are such an integral part of this course.

SECT I1: LEARNING OBJECTIVES

After the successful completion of this course, the following knowledge and skills will be obtained:

- Familiarity with allowable design stresses used to design a crane.
- Familiarity with some codes used to design cranes. With references listed for further study.
- How to perform Hand calculations to support any FEA analysis
- When to move to a 3D FEA to justify Stress calculations, and when hand calculations are sufficient
- How to specify and order some of the manufactured components within a crane

SECT 1.0: BASIC CRANE RATING AND THIS EXAMPLE CRANE

Most cranes are rated by both the reach and the elevation angle of the load lifted. A load chart is developed, and you can often see these on the side of the crane. This course focuses on a crane's max capacity at a o deg elevation angle, which is normally the worst case. Calculations for other angles are beyond the scope of this course. But these capacities will most often be fewer. Ratings at higher angles of elevation will be governed by bi-axial bending of the boom acting as a column with combined axial and bending loads. The charts on the sides of mobile cranes will define these capacities at various angles of elevation and reach.

This course uses the example of a crane rated for SOLAS (Safety of Life at Sea) standards. These standards are certified by a body such as ABS (American Bureau of Shipping), DNV (Det Norske Veritas, a Norwegian company), ECB (European Conformity Bureau), or other regulatory body.

The Solas Rating for this application is for 3500# = 2300# tender + 6 people @ 175# (Solas rated person)+ 150# allocated allowance. The crane must rotate this load and launch the tender as required, with the boat at 20 degrees list and 10 degrees of trim with the crane boom elevated up to max position when rotating against the incline.

Most mobile cranes are designed to operate on an incline of 5 degrees, but will rate them for 3 degrees.

Load Case #1) Crane basic rating (non-Solas) is for 10,000# @ 38ft reach. Does not need to rotate this load up an incline.

Load case #2) Crane basic rating (Solas) is for 3,500# @ 38ft reach.

See the next section for which load case governs the design.

Table GA lists allowable design stresses, which are discussed in section G1. See the list of references for further study for a more in-depth study of designing cranes.

This crane was actually built and used on a research vessel. See the following pictures in the figures document. The design of the rotation test stand was a project unto itself.

- R0TATION TEST: Tested at 23-degree incline angle
- ROTATION SLEW, WORM GEAR DRIVE
- FINAL ROAD TEST

Notice that it took 4 worm drives to rotate the load at the 23-degree incline and required speed!!

SECT G1: TENSILE AND ALLOWABLE STRESSES

The table displays the allowable design stresses used in the following design and other typical materials in KSI.

TABLE GA

	TS ksi/sq in	YS ksi/sq in	ABS (#2) Allowed Fb/Fv ksi/sq in	SOLAS (#3) Allowed Fb/Fv ksi/sq in	SOLAS Allowed Fbr ksi/sqin (#1)
Material					
5083-H116	44	31	15.5/9.77	9.77/5.98	17

5083-H116 by welds	40	24	14.4/8.88	8.88/5.3	N/A
5086-H116	40	28	14.4/8.6	9.33/5.57	12
6061-T6	45	40	16.2/9.7	10/5.98	19
6061-T6 by welds	29	17-20	10.4/6.26	6.44/3.87	N/A
					26
316 Stainless	75	30	15/9	16.66/9.9	21.6
17-4 PH Stainless	145	125	52/32	32/19.7	41.6
ASTM A-36 Steel	58	36	21.6/14.4	12.8/8.5	26

Note #1) SOLAS allowable bearing stress, from Ref 8; Aluminum Association Standards, Table 3, Engineering Data for Aluminum Structures. Then reduced to meet SOLAS standards.

Note #2) Reference #1 was used to obtain the ABS values.

Note #3) SOLAS

SOLAS stands for Safety of Life at Sea and applies to rescue craft aboard larger vessels. These higher safety factors may be considered for applications of cranes or davits in emergencies where the vessel may be sinking and heeling over. The API standards Ref 7 could be consulted for higher dynamic and wind loads.

The ABS values could be used for most cranes in industrial settings where occasional or moderate daily use of well-defined loads is normal. Industrial safety factors can range from 2 to 3. For 6061-T6, that would be from 45/2 = 22.5 to 45/3 = 15. The ABS values are more on the conservative side of that spectrum.

Note the large difference in allowable stresses by welds for 5083 vs 6061-T6.

The SOLAS standard safety factor is ultimate strength/4.5.

This example crane is dual-rated. One rating for the SOLAS load of a 3500lb rescue Tender and 10,000lbs for a std crane capacity. Both at 38Ft of each.

For this crane, which load case requirement will govern the design?

10,000 x 38 (Load case 1) > 3500 x 38ft (Load Case 2) by 2.85 times

An STD crane design can handle 1.58 times more bending stress than a SOLAS crane. As the 15ksi ABS allowable bend stress for 5083 is 1.58 times more than the 9.77 ksi SOLAS allowable from Table GA, above.

As 1.58 x 3500 = 5530lb is < 10000lbs, the 10000lb capacity will still govern most of the design, and the ABS allowable stresses for a basic crane will be used.

SECT M: MAJOR MECHANICAL COMPONENTS

These components are generally purchased and have longer lead times.

Sect M1.0 Actuator for cranes on a fairly level surface:

A rotary actuator is often used to rotate the crane turntable bearing and is mounted at the centerline of the turntable bearing. Industrial cranes will generally use a pinion gear with a hydraulic motor. The rotational torque required would be the same for both types of rotation devices at the turntable bearing. If a pinion is used, the gearbox torque required would be a function of the gear ratio between the pinion gear and the pitch diameter of the turntable bearing. So, it would be less torque required at the pinion or the gearbox driving the pinion, but the pinion RPM would need to be more.

Frictional torque on a rotary turntable bearing on a fairly level surface should be about 4.5 to 5% of the moment for a boom elevation of 0 degrees. As the test was conducted on a 1500lb capacity crane in a shop I was in.   Actuator torque values at this level will see periodic problems with rotating the load. Published values are available from manufacturers, which may provide different variables. A 'fairly level" surface is generally below 1 to 1.5 degrees of list. In order to operate satisfactory, the minimum torque should be about 7-8% of the live load and dead load for cranes under 100FTK of moment. Standard Mobile truck-mounted cranes are also designed to operate at +/- 5 degrees, but are generally not allowed to operate above +/- 3 degrees. Above 100FTK, the dead load of the crane must also be considered. Note that manufacturers of pinion gear turntable bearings list larger recommended values for mobile cranes, which generally operate on inclined grade. Plus, additional safety factors depending on the application and how hard the crane is used. These catalogs will need to be consulted to finalize a turntable bearing selection.

For grade inclines above 1.5 degrees, the torque required to rotate the crane arm up the incline will quickly become the dominate factor in selecting a rotation device, as will be seen in section M1.1.

Mobile cranes will have a minimum incline that they must operate in. This could be 5 degrees or more. This Torque load must be added to the 7-8% for a level surface.

Sect M1.1 SOLAS Rotational Torque on inclined surface:

Rotating a crane on a larger incline must overcome the rotational torque of the incline, which has a force of:

Pt = W x sin (theta),

where Pt = force in-lbs., W = Vertical load, theta = angle of incline.

R = Horizontal reach from the centerline of a ve ... oint of the turntable bearing to the vertical axi ... hen the boom is at the slew angle shown ... ese distances.

The Live load Mon ...

ML = live l ...

The dead load mom ...

R/2 is the approximat ... s, the actual CG distance should be us ...

DL = dead loa ...

The actual moment on t ... and the rotational slew angle of the crane b ... e will actually be a function of W x cos theta ... only contributes to the rotational torque r ... turntable bearing, which can vary with lubrication and bearing de ...

The example crane used in this course is a SOLAS crane and requires an incline of 20 List and 10-degree trim, for a total incline = SQRT (20x20 + 10x10) = 22.36 degrees (say 23).

Live Load = 5380#, LL = 5380

DEAD LOAD, DL = 5272#

Horizontal Reach R = 477.5-21.4 = 456 inches. (FIG M2.0-A BOOM and CABLE CYLINDER)

This is reached at 0 degrees of Boom elevation. Measured from the CL of rotation, which is also the CL of rotation of the 23-degree incline.