



USE OF ANSYS FOR CALCULATING GROUND BEARING PRESSURE UNDER CRAWLER CRANE TRACKS AND PAD LOAD UNDER THE OUTRIGGERS OF HYDRAULIC CRANES

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Abstract: Maintenance and assembly of modular projects in the heavy construction industry rely predominantly on high capacity mobile cranes of which hydraulic and crawler cranes are the most widely used. Because of the weight of the modules that are to be lifted, which nowadays can be expressed in hundreds of tons, ensuring proper ground integrity under the lifting equipment is paramount since its failure can result in dire consequences for the workers and the project. As a result, the first order of business, before selecting a crane for a specific project, is to evaluate the expected pressure under the tracks (or the outriggers) in order to determine the necessary ground treatments in order to make the lifting operation safe. In contrast to the traditional approach, where equations from statics are used to determine the pressure at specific points, the contribution presented in this paper adopts a continuous perspective by using finite element analysis (FEA). In this context, the pressure analysis yields a continuous map that can provide a more accurate view of the load distribution. Furthermore, the output of the proposed FEA-based approach will be used in the present study as an alternate source of data that can be compared to the results of the traditional statics method (widely used by crane companies).

1 INTRODUCTION

The modern heavy construction industry is increasingly adopting modularization as its primary design and project delivery paradigm. While a multitude of reasons have paved the way for using this paradigm, the most important of these may be the possibility of shifting a major portion of the work from the construction site to an indoor environment. In this context, projects are broken down into elements (known as modules) that are fabricated independently in a controlled environment, leaving a single activity to be carried out outdoors, namely the assembly of these modules. Because indoor fabrication can be viewed as a variation of manufacturing, many of the production systems that have been developed for the latter could easily be repurposed for the fabrication of modules. As a result, over time, designing and fabricating modules has become an efficient operation which encourages engineers to front-load these modules with an increasing number of functionalities to minimize on-site work. However, the drawback of maximizing the functionalities of a module is the resulting weight, which, a few decades ago measured a few tons, and has jumped in recent years to tens if not hundreds of tons. With the emergence of this new weight constraint, a new generation of lifting equipment characterized by their high capacity has been developed. However, this high

capacity is synonymous with increased structural complexity and heavier weights. On the construction site, to ensure that cranes can operate safely, the first order of business is to ensure that the bearing capacity of the ground can accommodate the pressure due to the compounded weights of the crane and payload. In this respect, it is worth noting that most crane-related accidents can be linked to soil stability (11%), and mobile crane fatalities account for (approximately) 84% of all the fatalities involving cranes/derricks (Beaver et al. 2006). In major heavy construction projects, crawler cranes are often preferred since they are the preferred lifting equipment that can lift the heaviest man-made structures and, if necessary, can travel with the payload. In practice, the design of ground support for mobile crane stability requires the evaluation of the pressure under the tracks of the crawler crane (or the outriggers in the case of a hydraulic truck crane). Traditionally, this calculation is carried out according to a procedure where the weights of the crane-payload system components are assumed to be static forces that generate a pressure on the ground through the support layer usually in the form of mats, which are used to maintain an overall pressure that is below the ground bearing capacity. The carrier has a fixed center of gravity (COG) but the superstructure COG moves based on the lifting radius, angle of the boom, and the rotation of the boom. Shapiro et al. (2011) present in-depth details of the calculations covering all crane weights and their COGs (Lawrence and Jay. 2011). Currently, a multitude of software exists for implementing these equations; however, although these software programs have proven to be useful to heavy construction practitioners, their output is often limited to pressure values that are calculated at specific points selected beforehand by the user. As a result, using an alternative procedure built upon finite elements not only allows the pressure to be mapped in a quasi-continuous manner, but more importantly, provides a means to check the accuracy of previously-developed calculation tools. In the research presented in this paper, the calculation of the ground bearing pressure under the crawlers (or outriggers) is carried out using ANSYS simulation software (version 17.1). To establish a realistic setup for the analysis, a model of the crane is built on the ANSYS platform. Based on the weight of each of the crane's components, a map representing the distribution of the pressure exerted on the ground is built as the superstructure rotates, mimicking a real-life lift. Pressure values selected at specific locations from the ANSYS pressure map are compared with those calculated using the equations available in the literature. In conclusion, in general, FEA favorably agrees (within less than 1%) with the results obtained from the software used by crane manufacturers (or an Excel implementation of the statics equations). Discrepancies between FEA and more traditional approaches, when they occur, are traceable to inaccuracies in the location of the COG.

2 TRADITIONAL PRACTICE OF CALCULATING GROUND BEARING PRESSURE

2.1 Crawler Crane

For the ground bearing pressure (GBP) calculations, the primary components include the weights of the stationary and rotating parts of the crawler crane and their respective COG locations. The pressure under the track along the track length may vary from trapezoidal to triangular. According to Shapiro et al. (2011), if the sum of the vertical load, V , and rear moment, f_r , is greater than that of the front moment, f_f (in numbers), the pressure diagram is trapezoidal, and if the sum is less, then the pressure diagram is triangular (Hasan et al. 2010). The values of vertical load, rear moment, and front moment can be calculated as follows:

$$[1] V = \frac{W_c + W_u + W_b + W}{2wd_l}$$

$$[2] f_f = \frac{3[(W_b d_b + Wd + W_u d_u) \cos \alpha + (W_{cr} + W)x_0 + W_c d_c]}{w(d_l)^2}$$

$$[3] f_r = \frac{(W_b d_b + Wd + W_u d_u) \sin \alpha}{wd_l t}$$

where W_c = weight of the carrier; W_u = weight of the superstructure; W = weight of the load; W_b = weight of the boom; d_c = horizontal distance of COG of the carrier to the crane's rotational axis (positive towards front); d_u = horizontal distance of COG of the superstructure to the crane's rotational axis (positive towards front); d = lifting radius; d_b = horizontal distance of boom's (and boom accessories') COG to the crane's

rotational axis (positive towards front); x_0 = distance between centerline of the tracks and the crane's rotational axis (positive towards front); d_t = bearing length of the track; d_f = distance between the centerlines of tracks; w = bearing width of the track; and α = angle of boom slew from the front of the crane to the left side (see Figure 1).

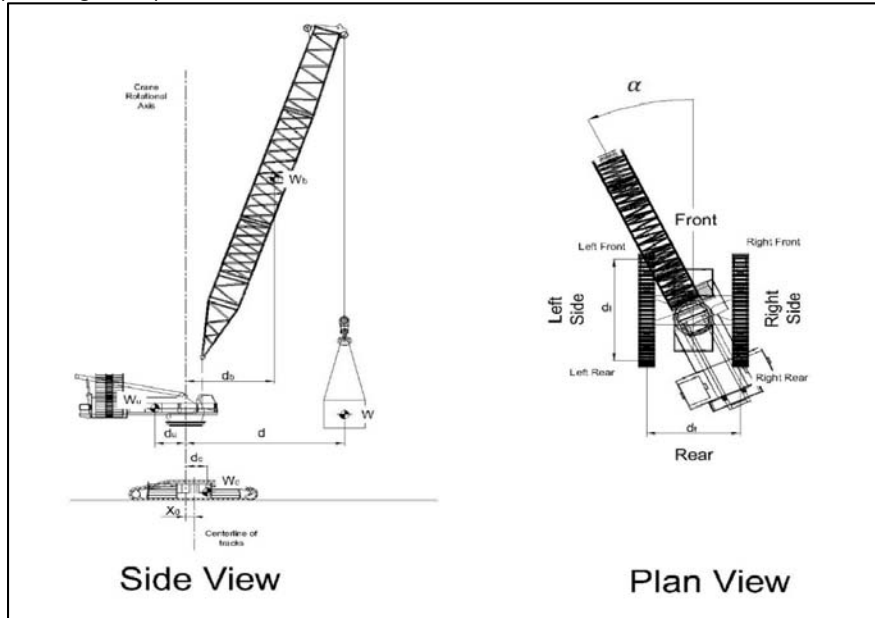


Figure 1: Parameters used for crawler crane GBP calculations

In cases where the pressure diagram is trapezoidal, Eq.1 to Eq. 3 can be used to calculate the GBP on the four sides of the tracks.

$$[4] \text{ GBP}_{(left\ front)} = V + f_r + f_f$$

$$[5] \text{ GBP}_{(left\ rear)} = V + f_r - f_f$$

$$[6] \text{ GBP}_{(right\ front)} = V - f_r + f_f$$

$$[7] \text{ GBP}_{(right\ rear)} = V - f_r - f_f$$

In cases where the pressure diagram is triangular, $\text{GBP}_{(left\ rear)} = 0$ and $\text{GBP}_{(right\ rear)} = 0$. The pressure on the left front and right front shall be expressed as,

$$[8] \text{ GBP}_{(left\ front)} = \frac{(W_c + W_u + W_b + W)d_t + 2[(W_b d_b + Wd + W_u d_u)\sin\alpha]}{w d_t}$$

$$[9] \text{ GBP}_{(right\ front)} = \frac{(W_c + W_u + W_b + W)d_t - 2[(W_b d_b + Wd + W_u d_u)\sin\alpha]}{w d_t}$$

$$[10] I = 1.5d_t - \frac{3[(W_b d_b + Wd + W_u d_u)\cos\alpha + (W_{cr} + W)x_0 + W_c d_c]}{W_{cr} + W}$$

The pressure variation is assumed to be trapezoidal or triangular along the length of the track (Hasan et al. 2010). It is clear that the pressure diagram along the width of the crawler will also be trapezoidal in nature, but it is considered uniform given that the pressure variation is minor.

2.2 Hydraulic Crane

The GBP calculations for hydraulic cranes are rather different from and simpler than those of crawler cranes. In hydraulic cranes, outrigger loads are applied in the form of forces under the outriggers. The

surface area of the outrigger mat is used to calculate the GBP exerted by that particular outrigger. The reaction forces under the outriggers are calculated using the following equations (see Figure 2):

$$[11] R_{(right\ front)} = \frac{W_c + W_u + W_b + W}{4} + \frac{1}{2} \left[\frac{(Wd + W_u d_u) \sin \alpha}{dt} - \frac{(Wd + W_u d_u) \cos \alpha + (W_c + W_u + W_b + W)x_0 + W_c d_c}{dl} \right]$$

$$[12] R_{(left\ front)} = \frac{W_c + W_u + W_b + W}{4} - \frac{1}{2} \left[\frac{(Wd + W_u d_u) \sin \alpha}{dt} + \frac{(Wd + W_u d_u) \cos \alpha + (W_c + W_u + W_b + W)x_0 + W_c d_c}{dl} \right]$$

$$[13] R_{(right\ rear)} = \frac{W_c + W_u + W_b + W}{4} + \frac{1}{2} \left[\frac{(Wd + W_u d_u) \sin \alpha}{dt} + \frac{(Wd + W_u d_u) \cos \alpha + (W_c + W_u + W_b + W)x_0 + W_c d_c}{dl} \right]$$

$$[14] R_{(left\ rear)} = \frac{W_c + W_u + W_b + W}{4} - \frac{1}{2} \left[\frac{(Wd + W_u d_u) \sin \alpha}{dt} - \frac{(Wd + W_u d_u) \cos \alpha + (W_c + W_u + W_b + W)x_0 + W_c d_c}{dl} \right]$$

where W_c = weight of the carrier; W_u = weight of the superstructure; W = weight of the load; W_b = weight of the boom; d_c = horizontal distance of COG of the carrier to the crane's rotational axis (positive towards front); d_u = horizontal distance of COG of the superstructure to the crane's rotational axis (positive towards front); d = lifting radius; d_b = horizontal distance of boom's (and boom accessories') COG to the crane's rotational axis (positive towards front); x_0 = distance between centroid of outriggers and the crane's rotational axis (positive towards front); d_l = distance between the outriggers lengthwise (center to center); d_t = distance between the outriggers widthwise (center to center); and α = angle of boom slew from the crane rear to the right front (Hasan et al. 2010). In this case, the pressure is considered uniform under mats.

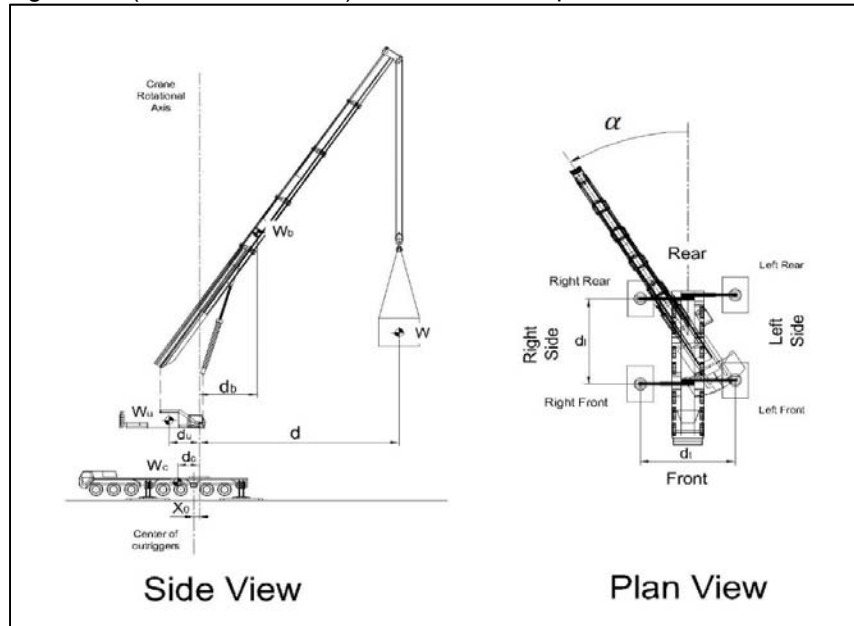


Figure 2: Parameters used for hydraulic crane GBP calculations

3 ANSYS BENCHMARK METHODOLOGY

3.1 Crawler Crane

Step 1: To develop the FEA model, the weights of various parts of the crane and their centroids are required, which are provided by the manufacturer of the selected crawler crane. This data is used to develop an algorithm for manual calculations using Eq. 1 to Eq. 10 for the GBP calculations with respect to the angle of the boom slew from the front to the left side of the crane. Boom slew angle increments are recorded every 5° from 0° to 90° . The obtained values are verified using the GBP software provided by the crane manufacturer. This prerequisite check is carried out to ensure the authenticity of the available data.

Step 2: The next step is to develop a crawler crane model. For this, all the major dimensions of the crawler crane under investigation are obtained from the 3D AutoCAD drawing of the model. ANSYS Workbench (version 17.1) is used to carry out the FEA in the present research. All parts (carrier, superstructure, boom, mast, and load) are assumed to be rigid. In general, the load-bearing length of the track is smaller as compared to the actual length of the track and in the case of a solid surface, the effective width is also shorter as compared to the actual width of the track. To obtain these readings, a thin plate (≈ 25 mm thick) of dimensions equal to the bearing length and the bearing width is placed under each track. This thin plate functions as a sensor to obtain the values for the pressure exerted by the tracks.

Step 3: The developed crane geometry is uploaded to a static structural mechanical workbench APDL solver. The stiffness behaviour of all crane parts is assumed to be rigid to consider forces only, with the exception of the thin plates under the tracks, which are assigned flexibility in order to measure the track pressure. The lowermost surface of the plates is loaded with fixed support. The weights and COGs of the various crane parts are adjusted by adding material blocks until the overall weight and COG of each part corresponds with the available data. The model is then loaded with gravity. After the model is solved, the results are assumed to be normal stress and minimum principal stress. (When only the three normal stresses remain, and all the shear stresses are zero, these normal stresses are known as principal stresses.) ANSYS provides negative values of principal stresses due to compression. The top surface of the thin plate and the lower surface of the track are assumed to be bonded. In the case of triangular pressure distribution, ANSYS provides negative values within the triangular region (I) (Eq.10) and positive values outside the triangular region (d_1-l) considering it as tension rather than compression. The positive values are ignored and the values within the region (d_1-l) are considered as zero.

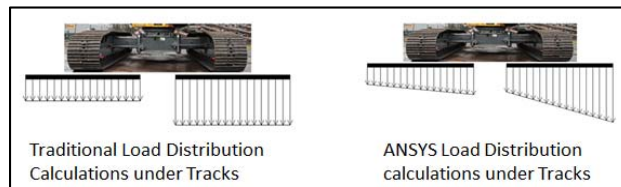


Figure 3: Traditional vs ANSYS load (compressive stress) distribution under tracks of a crawler crane

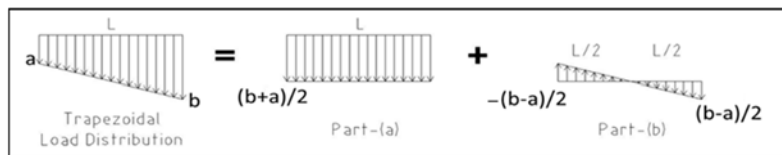


Figure 4: Trapezoidal load (compressive stress) converted into two parts (Liu and Gerbrandt 2008)

Step 4: The final step is to compare the results from ANSYS and the values from the manual calculations using the algorithms provided in the literature. Traditionally, widthwise pressure distribution under the track of the crane is considered uniform (Lawrence and Jay. 2011). But in reality, the widthwise pressure distribution diagram is trapezoidal in nature (see Figure 3). For this reason, ANSYS provides two values for each side of the track, one maximum and one minimum. To compare with the traditional calculations, only one value is required from ANSYS. This is achieved by dividing the trapezoidal pressure diagram into two parts, as can be seen in Figure 4, rectangular uniform stress in the form of a rectangular pressure diagram, and two triangular pressure diagrams with maximum and minimum stresses in opposite directions. The total compressive stress can be written as (Liu and Gerbrandt 2008),

$$[15] \text{ Total Compressive Stress} = \frac{(b+a)}{2} - \frac{(b-a)}{2} + \frac{(b-a)}{2}$$

$$[16] \text{ Total Compressive Stress} = \frac{(b+a)}{2}$$

The value obtained from Eq. 16 is compared with the traditional calculations (Liu and Gerbrandt 2008). The entire process creates three sets of values: (1) from the manufacturer’s software, (2) from the manual calculations, and (3) from ANSYS analysis. The first two sets of values are based on Eq. 1 to Eq. 10, but the third set of values does not rely on these equations. The third set of values employs FEA to calculate the pressures under the tracks. Figure 5 presents the data flow for a crawler crane.

3.2 Hydraulic Crane

Step 1: This step is similar to Step 1 for the crawler crane. The weights and the COGs of all the major parts of the hydraulic crane are required. These are obtained from the hydraulic crane model manufacturer.

Step 2: The model of the hydraulic crane is developed in ANSYS mechanical workbench. All crane parts (carrier, superstructure, hydraulic boom, and load) are assumed to be rigid. Given that only the reaction forces are required, rather than those of the thin plate, crane mats are used for crane ground support and load reading.

Step 3: The hydraulic crane geometry is uploaded to a static structural mechanical workbench APDL solver. The stiffness behaviour of all parts is assumed to be rigid in order to consider forces only, with the exception of the outrigger mats. The lowermost surface of the outrigger mats is loaded with fixed ground support. All parts of the cranes are assigned with their respective weights and COGs. The weights and COGs are then adjusted by adding material blocks to the particular parts with various density and location until the overall weight and COG of the part corresponds with the given data. Once the model is solved, the solution is applied in the form of reaction forces on all four outriggers.

Step 4: The final step is to compare the results from ANSYS, the values from the manual calculations using the algorithms, and the load values obtained from the manufacturer’s software. The entire process creates three sets of values, just as in Step 4 for the crawler crane in Section 3.1. Two sets of values are generated using Eq. 11 to Eq. 14. Figure 5 presents the data flow for a hydraulic crane.

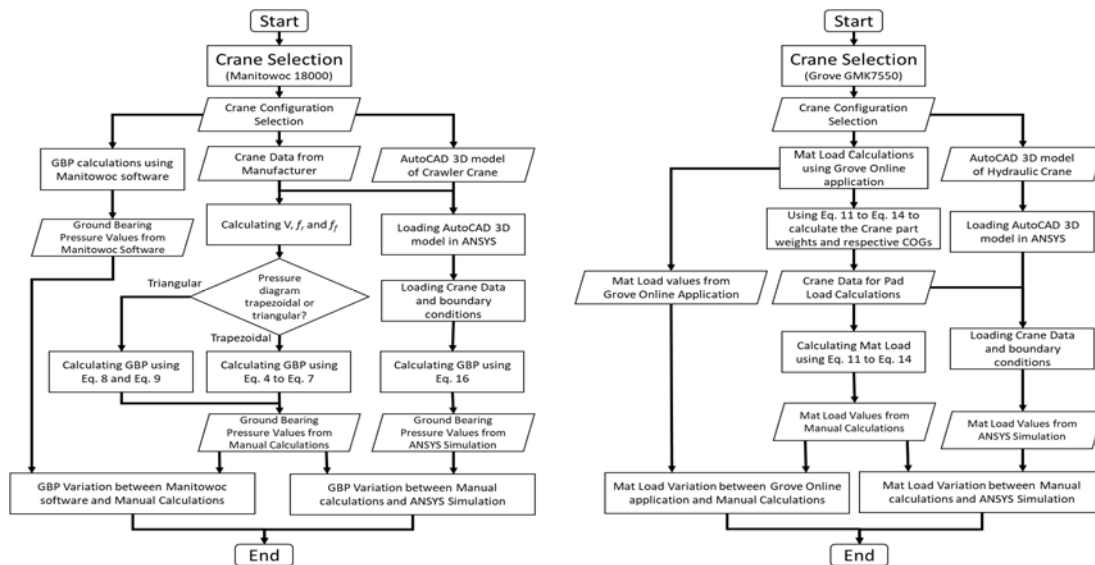


Figure 5: Flow chart for crawler crane and hydraulic crane data flow

4 ANSYS BENCHMARK CASE EXAMPLES

4.1 Crawler Crane (Manitowoc 18000)

The first case example involves the Manitowoc 18000 crawler crane. The length of the boom (#55 or #55A) is input as 280 ft (85.344 m), carbody counterweights as 320,000 lb. (145,150 kg), upper counterweights as 528,000 lb (239,500 kg), and operating surface as rigid. For this case study, three different loads at three

different lifting radii are tested using ANSYS. The AutoCAD model is imported into the ANSYS geometry module. The parts of the crane are segregated into three major parts: upper, lower, and steel plates (stress sensors). The boom angle with the ground's surface is adjusted to obtain the required lifting radius. A dummy block of material is used as the load for this crane, and the density of the dummy block is altered to obtain the required weight of the subject load. Given that the investigation is carried out for the three different loads, three different geometries are developed, respectively.

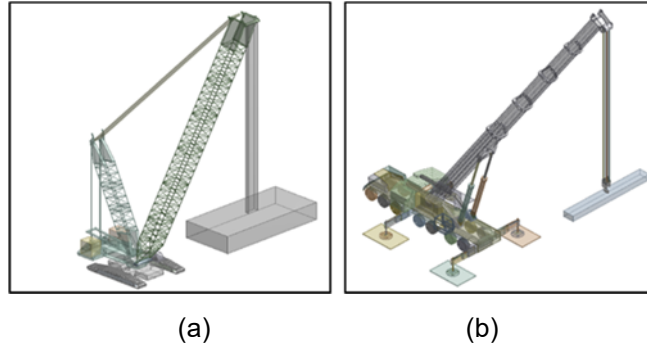


Figure 6: (a) Manitowoc 18000 Model and (b) Grove 7550 Model in ANSYS Mechanical Workbench

Each geometry is uploaded to the static structural mechanical workbench APDL solver (see Figure 6). Identical weights and respective COGs are used for the algorithm in order to obtain a manual set of GBP data for the boom slew angle from 0° to 90° (crane front to crane left side). The same configuration is used to obtain the GBP values from the manufacturer's software, "Manitowoc Ground Bearing Pressure Estimator Version: 1.0.6.0", which is available as freeware from the Manitowoc official website (Manitowoc 2017). This process is carried out in order to obtain two sets of values, one from manual calculations and one from company-provided software (see Figure 5).

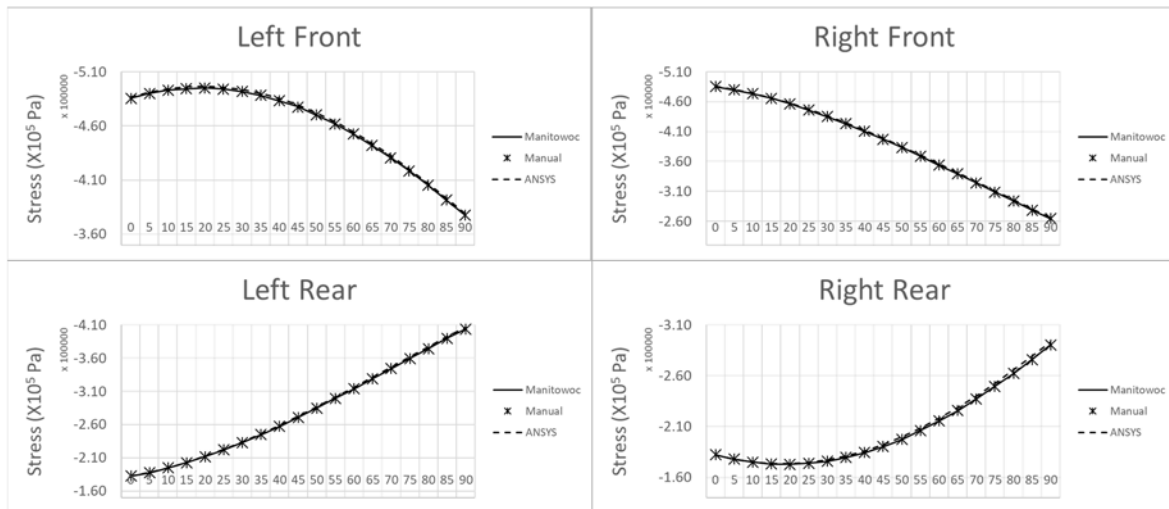


Figure 7: GBP (minimum principal stress) values from Manitowoc software (Manitowoc 2017), manual calculations, and ANSYS simulation calculations on four sides of crawler crane, Manitowoc 18000, along boom slew angle from 0° to 90° from front to left side with load of 110,231.13 lb (50,000 kg) at lifting radius of 85 ft (25.917 m)

The next task is to obtain the GBP values from the ANSYS solver. The first crane geometry is taken at the lifting radius of 85 ft (25.917 m) with the load of 110,231.13 lb. (50,000 kg). Table 1 presents the crane configuration details for each case example. The geometry of the crane model is loaded as described in Step 3 for crawler cranes in Section 3.1. The model is loaded with the boundary conditions. The upper part of the crane is rotated from 0° to 90°. The model is then solved using the static structural mechanical APDL

solver. The top surface of the thin plate under the tracks is used as a sensor for the stresses in the form of normal or minimum principal stresses. All major crane parts are rigid in nature; thus the minimum principal stresses are similar to normal stresses. For the purpose of comparison, minimum principal stresses are utilized instead of normal stresses. Eq. 16 is applied to obtain the single value along the track.

The difference between the manual calculations and Manitowoc software values are noted. The percentage of variation is measured against the largest value. The percentage variation error between the manual calculations and Manitowoc software is approximately 0.054%, which is much less than 1%. The values of GBP from ANSYS are also obtained. Using Eq. 16, one set of ANSYS values is obtained and compared against the manual calculations. The percentage of error between ANSYS and the manual calculations is approximately 0.518%, which is also less than 1%. The GBP values from all three sets with respect to the boom slew angle from 0° to 90° from the front to left side of the crane are presented in Figure 7.

For the second load example, the crane geometry is input as the lifting radius of 70 ft (21.336 m) with the load of 165,346.69 lb. (75,000 kg). The percentage variation between the manual calculations and Manitowoc software is approximately 0.049% (much less than 1%). The percentage of error between ANSYS and the manual calculations is approximately 0.506%, which is also less than 1%.

For the third load example, crawler crane geometry is input as the lifting radius of 65 ft (19.812 m) with the load of 220,462.26 lb. (100,000 kg). The percentage variation between the manual calculations and Manitowoc software is approximately 0.036% and the percentage of error between ANSYS and the manual calculations is approximately 0.473%. The variation of GBP values is presented in Table 1.

Table 1: Variation of GBP values between Manitowoc, manual, and ANSYS calculation (Manitowoc 18000)

Description	Manual calculation input values		ANSYS input values		
	Weight (Ton)	COG distance (m) from CL of rotation	Weight (Ton)	COG distance (m) from CL of rotation	
Boom	118.358	11.256	118.360	11.270	
Upper	346.351	-5.985	346.350	-5.985	
Crawler	249.719	-0.176	249.720	-0.176	
Length of Bearing Crawler		8.839		8.840	
Distance Between Crawler		8.534		8.534	
Load 1	50.000	25.917	49.998	25.917	
Load 2	75.000	21.336	74.996	21.358	
Load 3	100.000	19.812	99.996	19.812	
	Variation (%)		Load 1	Load 2	Load 3
	Variation (%) between manual and Manitowoc Software Calculations		0.054	0.049	0.036
	Variation (%) between manual and ANSYS Calculations		0.518	0.506	0.473

4.2 Hydraulic Crane (Grove GMK 7550)

Grove GMK7550 is selected for the second case example. Grove GMK7550 is a hydraulic all-terrain crane. The boom of the crane is input as 125.1 ft (38.13 m) [0-100-100-0] with superstructure counterweights as 264,500 lb. (119,975 kg). The lifting radius is input as 65 ft (19.812 m) with the load of 88,185 lb. (40,000 kg). The surface operating condition is input as solid with an outrigger span of 28.7 ft × 29.2 ft. In the case of hydraulic cranes, the manufacturer’s software and manual calculations only provide the load in the form of force on each outrigger. This reaction force is divided by the area of the mat to obtain the GBP. In the present research, only the mat loads are compared rather than GBP. An online application for pad/mat load calculations is available from the hydraulic crane manufacturer (Grove 2017); however, it only provides outrigger loads at particular angles with the increment of 45°. For this case example, the boom angle is input from 0° to 360° from the rear to right side at an increment of 45° for manual and online software comparison. Then, the manual calculations based on the same crane configuration and data is developed from the boom slew angle of 0° to 90° from the rear to right side (see Figure 5). These manual calculations are compared with ANSYS values.

The set of manual calculations are obtained from Eq. 11 to Eq.14. These values are then compared with the online Grove application calculations. The percentage variation between the manual calculations and the Grove online application values is approximately 1.66%. The reason for the higher variation is that the weights of each part and their respective COGs were not available from the manufacturer, but rather the pad loads were available from the online Grove application at various angles. By utilizing these pad load values against different angles and the use of Eq. 11 to Eq. 14 with weights and COGs as unknown variables, the required data is obtained (see Figure 5). The values of weights and COGs are adjusted to minimize the error (1.66% with respect to the largest value). The values of manual calculations and Grove online application values are then plotted against the angle of boom slew from 0° to 360° from the rear to right side of the crane at an increment of 45° (Figure 8).

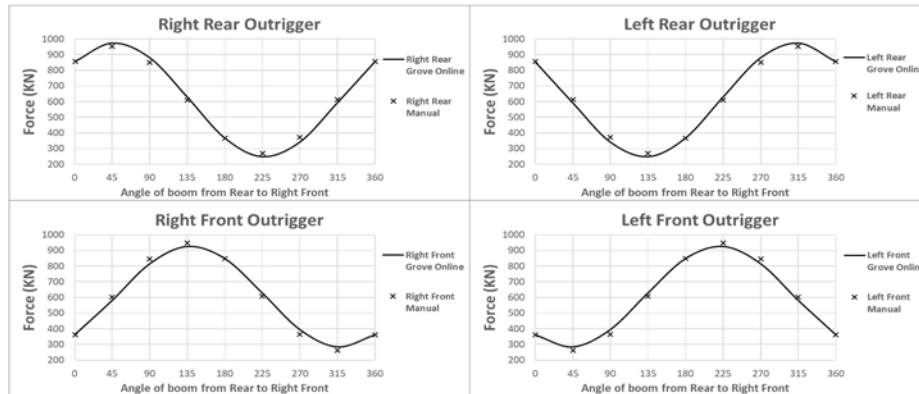


Figure 8: Pad load values from Grove online application (Grove 2017) and manual calculations for the four outriggers of the hydraulic crane, Grove GMK7550, along boom slew angle from 0° to 360° from rear to right side of crane with load of 88,185 lb. (40,000 kg) at lifting radius of 65 ft (19.812 m)

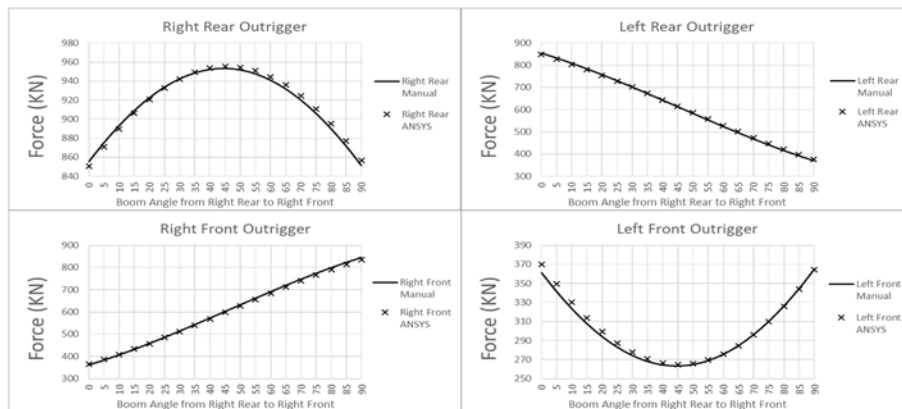


Figure 9: Pad load values from manual calculations and ANSYS simulation of the four outriggers of the hydraulic crane, Grove GMK7550, along with boom slew angle of 0° to 90° from rear to right side of crane with load of 88,185 lb. (40,000 kg) at lifting radius of 65 ft (19.812 m)

The values of part weights and their respective COGs are used to develop the ANSYS geometry. The density of the dummy load block is altered to obtain the required weight of the subject load. The geometry of the crane model (see Figure 6) is loaded with the respective weights and COGs as described in Step 3 for hydraulic cranes in Section 3.2. The model is loaded with the boundary conditions. The upper part of the crane is then rotated from 0° to 90°, and the model is solved using the static structural mechanical APDL solver. The top surface of the mats is utilized as a sensor for reaction forces. The values from ANSYS are plotted against manual calculations as presented in Figure 9. The variation in the values is approximately 0.37% (with respect to the largest value), which is much less than 1%.

5 CONCLUSION

The cases presented in this study (crawler and hydraulic crane case examples) are used to develop a GBP benchmark for ANSYS. The values from ANSYS are compared with the manual calculations based on Eq. 1 to Eq. 14, and the values from the crane manufacturer's software. The following conclusions can be drawn:

- It is observed that along the track width, a variation of ground pressure values exists in the form of minimum and maximum values. The pressure diagram along the width of the crawler crane track is also trapezoidal in nature. In manual calculations, the pressure diagram along the width of the track is taken to be uniform in nature. Eq. 16 is used to calculate a single value for the comparison.
- The crawler crane ground bearing pressure calculations variation, in terms of percentage between all three sets of values, is proven to be less than 1%. This indicates that ANSYS can be used as an alternative to calculate the ground bearing pressure under the tracks.
- This is also the case for hydraulic cranes. The percentage of variation between manual calculations and ANSYS values is proven to be less than 1%. This also indicates that ANSYS can be used to calculate the load values under the outriggers of a hydraulic crane.
- ANSYS effectively provides the simulation of GBP/pad load variation along boom slew angle 0° to 90° .

6 RECOMMENDATIONS AND FUTURE ASPECTS OF THE RESEARCH

This research indicates that ANSYS can be used as an alternative for the ground bearing pressure calculations rather than manual calculations or manufacturer-provided values given that all the required data is available to develop an ANSYS model. This method can be used to check the authenticity of the ground bearing pressure calculation software available in the market. In the case where the part weights and COGs are equal, it can be observed from the present research that ANSYS also provides the same values as the Manitowoc software and the manual calculations. If the difference is great, an error exists in the software calculations. A benchmark for crawler cranes and hydraulic cranes is developed in ANSYS, which can be used to observe the crane mat deflection and stress variation under the mats with different mechanical properties. Various crane models and soil models can be developed to observe the ground deflection under crane loading. This ANSYS crane model can be used to develop and test new mat types, which can benefit the expanding crane mat market. In 2014, GEMS conducted market research to assess the mat market in Canada for future company growth. According to their research, the total mat demand in Canada alone is between 450,000 to 750,000 per annum, whereas annual mat production in North America is between 300,000 to 600,000. Potential growth areas for the crane mat industry is the emergence of composite mats due to their durability and lighter weights, as well as the reduced cost of transportation (GEMS 2015). ANSYS can be used to analyze the behaviour of these proposed mats under loading.

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