Analysis and Design of Crane Beam of Experimental Power Plant Turbine Building

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Abstract. The turbine building is one of the main buildings in the experimental power plant (RDE). Turbine and condenser generators are the main components of the turbine building. The total weight of the generator and condenser is about 80 tons. It is estimated that the toughest parts of turbines and condensers are about 20 tons. The turbine building will be equipped with an overhead crane double girder. The benefits of cranes are as lifting equipment to assist the installation and maintenance of generators and condensers. The purpose of this paper is to design and analysis of the planned RDE turbine beam crane building. The method used is Load Resistance Factor Design or called LRFD methods. Some of the standards used include AISC Design Guide 7 second edition and CISC Crane Guide second edition. Based on the basic drawing of the turbine building design, the distance of the crane supporting column is 14 meters. It is planned that the total length of the girder crane is 13 meters. Weight hoist and trolley 2,950 kg and double girder 10,120 kg selected from one vendor crane product. The results of the calculations and checks show that the W shape with Cap Chanel W27x84 C15x33.9 is safe to used.

Keywords: beam, crane, turbine building, RDE, LRFD, design.

1. Introduction

The Experimental Power Reactor (RDE) [1] is a non-commercial nuclear power plant planned to be built in the Puspiptek Serpong area. In nuclear power reactors, reactor buildings and turbine buildings are the main buildings that are separated from one another. The reactor building is an operational building of a nuclear reactor and a steam generator whereas the turbine building is where the turbine generator is located. The RDE turbine generator is an RDE component that acts as a powerhouse. This generator is a vital and expensive equipment of a power plant [2] after the RDE nuclear reactor. Based on basic design engineering RDE [3], turbine building is building with steel construction equipped with crane of building.

Cranes are lifting equipment used to help unload - install turbine generators and their components. Crane is a tool in the placement of turbine generators and other equipment during initial installation and during inspection and maintenance. The capacity of the turbine crane building is planned to be 20 tons. Crane will be placed on a beam that can move in the direction of the beam axis. Beam cranes can move perpendicular to the axis of the beam crane. The purpose of this research is to design and analyze the beam crane of the planned RDE turbine building. Analysis is needed to produce a good, robust, efficient
and economical design. Analysis and design of the beam crane will be used further in the turbine building design process as a live load.

The method used is Load Resistance Factor Design (LRFD). Standard used is AISC Design Guide 7 second edition [4] and CISC Crane Guide second edition [5]. Software used is CivilBay online software. Based on the basic drawing of the turbine building design, the distance of the building column to the crane crossing is 14 meters. It is planned that the total length of the girder crane is 13 meters. Weight hoist and trolley 2,950 kg and double girder 10,120 kg selected from crane vendor. If the crane capacity of 20 tons and the runway beam section type is W shape with cap channel according to AISC standard then the W and C combination section size that meet the safe requirements is W27x84 and C15x33.9 [6]. Usually there are two types of material that are popular in building construction, namely steel and concrete [7], in some steel construction buildings some columns are made of concrete. In turbine building design all columns and beams are designed using a wide flange (W) steel profile.

2. Theory
Overhead cranes are widely used in various fields, such as heavy industry, seaports, automotive factories, and construction facilities [8] as well as special buildings such as reactor buildings and powerhouse turbine buildings. Catastrophic crane failure is a potentially very dangerous and often fatal event [9]. Therefore, good crane planning and a careful fabrication process will produce a good overhead crane system. In general beam cranes and other parts of the overhead crane system especially the type of bridge is as shown in Figure 1

![Figure 1. Double girder electric overhead crane](image)

2.1. Loading on Structure
Loads are factors that must be taken into account in the design. In the building turbine beam crane planning, the following types of loads need to be taken into account, namely:

- **Dead load**
  The frame weight is a dead load, coming from all of the things that are attached to the frame [9]. Indonesia National Standard (SNI) 1727 of 2013 defines that the dead load is the weight of all building construction materials installed, including walls, floors, ceilings, stairs, fixed partition walls, and finishing of buildings and other architectural and structural components and equipment. Installed services include crane weight [11]. The dead load will be called DL.

- **Live load**
  Life Expenses are burdens that change in structure and are not fixed. In the turbine building, the cranes and bridges and the maximum crane capacity can be considered as live load.
2.2. Load combinations

In the case of turbine building design the load factor is combined between dead load, live load and earthquake load. Arrangement of load combination refers to the SNI 1727 standard in 2013. The minimum combination of loading arrangements is a combination of basics. Structures, components and foundations are designed so that their design strength is equal or greater than the effect of the factored load in combination [11].

2.3. Method and Standards

In this paper the method used is the LRFD method. There are two calculated loads, Wheel load by bridge self-weight \( P_{br} \) as dead load and Wheel load by bridge self-weight \( P_{lt} \) as live load. In LRFD method, the loading factor for dead load is 1.2 whereas for live load is 1.6. The load on the crane using the LRFD method can be calculated using the following formulas of Crane load for AISC LRFD design:

Wheel load by bridge self-weight
\[
P_{br} = \frac{W_{br}}{\text{number of wheel} \times 2 \text{sides}}
\]  

Wheel load by lift load and trolley
\[
P_{lt} = P_{max} - P_{br}
\]  

Maximum factored vertical load/wheel
\[
P_{v-f} = 1.2 \times P_{br} + 1.6 \times P_{lt}
\]  

Maximum factored horizontal load/wheel
\[
P_{h-f} = 1.2 \times P_{br} + 1.6 \times P_{lt}
\]

In the formula (1), the value of bridge weight \( W_{br} \) can be obtained from the vendor's catalog. Maximum static load \( P_{max} \) is the maximum load that counts. Maximum static load is selected from the highest value between maximum wheel load by calculation \( P_{max-c} \) with maximum wheel load by vendor \( P_{max-v} \). Maximum wheel load by calculation \( P_{max-c} \) is calculated by summing crane rated capacity \( W_{rc} \) and trolley & hoist weight \( W_{th} \) multiplied by the difference of crane bridge span \( S_{r} \) value to minimum hook approach \( S_{min} \) formulated as:
\[
P_{max-c} = \frac{(W_{rc}+W_{th})(S_{r}-S_{min})}{\text{number of wheel} \times S_{r}} + P_{br}
\]  

while the maximum wheel load by vendor \( P_{max-v} \) value is obtained from the catalog of crane manufacturers.
\[
P_{max} = \max(P_{max-v}, P_{max-c})
\]

While the minimum static wheel load \( P_{min} \) is defined as:
\[
P_{min} = \frac{(W_{rc}+W_{th})S_{min}}{\text{number of wheel} \times S_{r}} + P_{br}
\]

So, the free bridge crane object diagram of the vertical load to determine the maximum bending moment and deflection can be described as Figure 2.

![Figure 2. Free body diagram bridge crane](image-url)
By using the free body diagram in Figure 2 the maximum member forces for the crane runway beam design can be calculated the value of maximum unfactored moment and moment by moving wheel load at distance x. It can also be calculated maximum unfactored shear and shear by moving wheel load at a distance of x. In this case x represents the maximum distance the occurrence of the moment on the crane block beam.

Factor bending moment x-x axis:

\[ M_x = \frac{M_{cr} \times P_{v-f}}{P_{max} \times a(impact)} + Msw \times 1.2 \]  \hspace{1cm} (8)

Factor bending moment y-y axis:

\[ M_y = \frac{M_{cr} \times P_{h-f}}{P_{max}} \]  \hspace{1cm} (9)

Factor shear along y-y axis:

\[ V_y = \frac{V_{cr} \times P_{v-f}}{P_{max} \times a(impact)} + Vsw \times 1.2 \]  \hspace{1cm} (10)

The maximum deflection is obtained at a distance of x meter in the form of a deflection by moving wheel load \((D_{cr})\) value of a certain value.

Check local buckling is done on the W shape profile selected. W shape classification includes flange of W shape, web of W shape, flange of channel, and bending about x-x axis. So that local buckling checks calculations using AISC 360 standard. The use of CivilBay software can give the calculation result check local buckling pad flange of W shape and web of W shape. \(M_s\) bending about x-x axis can also be obtained so that with LRFD method moment value \((M)\) at x meter distance can be obtained by \(M_s\) with deflection equal to f. Secure conditions are met if the ratio of \(M_s\) to deflection if:

\[ r\text{atio} = \frac{M_x}{fM_{ns}} \leq 1.0 \]  \hspace{1cm} (11)

3. Methodology

To be able to realize the purpose of analysis and design of the RDE turbine building beam crane this research used static calculation method and also using online software CivilBay. Power calculation and analysis are also done by making a beam crane stretch model. Beam crane size refers to basic engineering design (BED) turbine building RDE as shown in Figure 3.

![Figure 3](image-url)
Figure 3(a) shows up the turbine building for a level of 0.0 m. At the 0.0 m level it is seen that the crane service area width is 14 m center to center. This service width becomes the reference of the length of beam crane which is the way for the crane to move. Furthermore, Figure 3(b) shows the side view of the building. It is seen from the side. It is seen that at -6.5 m level turbine generator is laid. Generator turbine is the main tool that will be served by crane building. The turbine weighs is about 80 tons. If the crane is planned as a tonnage and tidal support equipment then a 20 ton capacity crane can be planned with a beam crane as shown in Figures 4. The design data is shown in Table 1.

**Table 1.** Design data of the experimental power plant turbine beam crane [3][5][12]

| Parameter                        | Symbol | Nominal   |
|----------------------------------|--------|-----------|
| Crane rated capacity             | $W_{rc}$ | 20,000.0 kg |
| Bridge weight                    | $W_{br}$ | 10,120.0 kg |
| Trolley & hoist weight           | $W_{th}$ | 2,950.0 kg |
| Bridge wheel spacing             | $d_{l}$ | 3.7 m     |
| Maximum static wheel load        | $P_{max-v}$ | 17,282.0 kg |
| Crane bridge span                | $S_{r}$ | 13.0 m    |
| Minimum hook approach            | left $S_{L}$ | 1.2 m |
|                                  | right $S_{R}$ | 1.2 m |
| Runway clearance distance        | right $e_{L}$ | 0.5 m |
|                                  | left $e_{L}$ | 0.5 m |
| Crane runway beam span           | $L_{l}$ | 9.0 m     |

Sections should be numbered with a dot following the number and then separated by a single space:

**Figure 4.** Front and top view of turbine building beam crane design
Steel frame
Steel frame turbine beam cranes are made of Wide Flange (W) and C steel profiles AISC Table steel. The W and C profile cross-sectional shape as shown in Figure 5.

![Figure 5. W and C profile steel cross section](image)

4. Result and Discussion
Therefore, the weight of the turbine component that will use the crane of the building is estimated to be a maximum of 20 tons, then the crane capacity is 20 tons. Based on the calculations, the crane load for AISC LRFD design uses formulas (1) through (7) and data in Table 1 then the results of calculations with CivilBay software are as in Table 2.

| Parameter                                      | Symbol | Nominal          |
|------------------------------------------------|--------|------------------|
| Wheel load by bridge self-weight               | $P_{br}$ | 2,531 kg (dead load) |
| Maximum static load                            | $P_{max}$ | 17,282 kg (live load) |
| Wheel load by lift load and trolley            | $P_{lt}$ | 14,751 kg |
| Maximum factored vertical load/wheel           | $P_{v-f}$ | 26,640 kg |
| Maximum factored horizontal load/wheel         | $P_{h-f}$ | 1,688 kg |
| minimum static wheel load                      | $P_{min}$ | 3,520 kg |

The result of factor bending moment $x - x$ axis and factor bending moment factor $y-y$ axis and factor shear along $y-y$ axis as shown in Table 3. In addition, the calculation result for critical deflection is also obtained in Table 3. The ratio at the distance of $x$ is also shown in Table 3.

| Parameter                                      | Symbol | Nominal          |
|------------------------------------------------|--------|------------------|
| Factor bending moment $x - x$ axis            | $M_x$  | 84,345 kg-m      |
| Factor bending moment $y - y$ axis            | $M_y$  | 4,937 kg-m       |
| Factor shear along $y-y$ axis                 | $V_y$  | 45,287 kg       |
| Deflection moment $x - x$ axis                | $f$    | 0.0229 m at $x = 2.75$ m |
| Ratio                                         |        | 0.44             |
The use of CivilBay software allows for safe inspection of selected W27x84 and C15x33.9 steel profiles based on AISC Steel Construction Manual Table 1-19. Inspection of steel safety ratio refers to AISC 360 standard which includes bending ratio of the yy axis in the top flange - top running crane, biaxial bending ratio in the top flange, shear alongside axis ratio, and sides way buckling ratio as shown in Table 4.

| Parameter                                      | Ratio | Qualify |
|------------------------------------------------|-------|---------|
| Bending about the x-x axis                    | 0.44  | ok      |
| Bending about the y-y axis in the top flange – top running crane | 0.12  | ok      |
| Biaxial bending in the top flange              | 0.57  | ok      |
| Shear along y-y axis                           | 0.23  | ok      |
| Web sides way buckling                         | 0.57  | ok      |

Based on the results of the calculation of civilbay also obtained the value of runway beam vertical deflection ratio of 0.83 and runway beam lateral deflection ratio of 0.37 which both are eligible ok. All of ratio is overall ratio. The overall ratio of crane beam design is 0.83 qualify ok.

Finally, it was found that crane load imposed on building column for building design at x = 5.64 m maximum. The maximum support reaction value in the vertical direction of R1 is 29.475 kg and R2 is 7,453 kg. Point moment to building column center is M1 equal to 14,823 kg-m and M2 equal to 3,748 kg-m.

5. Conclusion

It has been established that the maximum capacity of the turbine building crane is 20 tons. Design and analysis were performed using AISC Guide 7 standard and CivilBay software. Weight bridge rail 10,120 kg, trolley and hoist 2,950 kg, and maximum static wheel load 17,282 kg obtained from vendor. The crane rail selected by AISC standard steel table in civelBay software is W27x84 and C15x33.9. Result of calculation and analysis obtained that at bridge, maximum deflection happened at distance of 2.75 meter equal to 0.0229 m with maximum moment Mx 84,423 kg-m. On the Runway beam with a length of 9 meters, maximum deflection occurs at a distance of 5.64 from the edge of the beam with a maximum moment of M1 of 14.823 kg-m and M2 of 3.748 kg-m. The reaction forces at the ends of the beam of R1 are 29.475 kg and R2 is 7,453 kg. Based on the results of the overall ratio examination of 0.83 and meet the requirements of safe conditions.

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