`PROSIDING SNTTM XXII 2024
Volume 22, Tahun 2024, 02 Oktober 2024

e-ISSN 2623 0331
p-ISSN 3032 1972

Maximum stress and deformation of coal flow breaker plate due to continuous coal bulk impact loading

Asnawi Lubis[a,1], Kiagus A. Hadi[b], Jamiatul Akmal[a], Zulhenfri Hasymi[a]

[a]Department of Mechanical Engineering, University of Lampung, Bandar Lampung, 35145
[b]PT. Bukit Asam Tbk., Pelabuhan Tarahan, Bandar Lampung, 35242

[1]asnawi.lubis@eng.unila.ac.id

ABSTRACT

Vibrating screens are very important equipment in the coal mining and processing industry. One of the components of this vibrating screen is a flow breaker plate which functions as a flow breaker for the coal bulk load before it falls on the vibrating screen. Due to the impact load of coal bulk which works continuously, the plate often breaks in fatigue with a maximum stress and deformation greater than those if the load worked statically. This paper aims to present the results of a finite element study of the maximum stress and deformation that occurs in several types of materials used as coal flow impact load breaker plates at PT Bukit Asam Pelabuhn Tarahan Bandar Lampung. The plate construction is modeled as beams with fixed at both ends. The length and height (as a beam) are 1500 and 200 mm respectively, while the plate thickness (beam width) is analyzed to be 15 and 20 mm for each type of material. Four types of materials available at PT Bukit Asam, namely ST37, ST52, Hardock (HB400), and GS20 Mns were analyzed for impact loads using ANSYS Explicit Dynamics. The results of finite element analysis show that the ST37 material with a thickness of 20 mm experiences the smallest maximum stress compared to the other three types of material. Meanwhile, for deformation, the analysis results show that ST52 material with a thickness of 20 mm experiences the smallest maximum deflection compared to the three other types of material.

Keywords: maximum stress, maximum deformation, flow breaker plate, coal bulk load

Received 2 September 2024; **Presented** 2 Oktober 2024; **Publication** 20 Januari 2025;
DOI: 10.71452/590781

INTRODUCTION

Coal is a natural energy source that is widely used as fuel for Steam Power Plants (PLTU). PT. Bukit Asam Tbk., is one of the Indonesian state-owned companies (BUMN) which operates in the coal mining and energy sectors. The coal supply is obtained from the mining location in Tanjung Enim, South Sumatera. This coal is then distributed to ports such as Kertapati Pier in Palembang and Tarahan harbour in Lampung.

Tarahan Port as the largest coal port in Southeast Asia, in its operations uses several main machines for processing coal, including Rotary Car Dumper, Stacker Reclaimer, Crusher, Vibrating screen, Barge Loader, and Shiploader. Vibrating Screen (sieve) as an important unit, functions as a filter for crushed stone and coal with sizes that are not suitable for the product to be sold, namely more than 50mm [1].

In the vibrating screen unit there is a component called coal flow breaker plates which is often damaged. These plates were broken due to the impact force of coal pouring which worked continuously from a height of 5 meters. The plate material is bulldozer cutting edge blade, which utilizes the company's stock of materials with mechanical properties as shown in Figure 1.

CUTTING EDGE			
Mechanical properties	Hardness	27-47	HRC
	Tensile	1100-1450	Rm-N/mm²
	Impact test	7-40	J
Material	High-carbon steel	80#	
	Boron steel	30MnB	
	Manganese steel	16Mn	
Different type	Double bevel curved	7T1626 3G7966 9W2313 4T3511 234-70-12670 9W2334 5D9731 7T1631 9W2330 9J7701	
	Single bevel flat	7V1490 7V0904 9V6573 4E0659 5V4696 6W2985 6W2989 5V7423 9V6574 12201	
	Double bevel flat	6Y0313 9W4495 6Y0018 9W2425 7T9782 8E2086 9W3930 1U1534 6Y5538 4T9590	
Application	Grader, Bulldozer		

Figure 1. Material *Cutting Edge Buldozer* [1]

e-ISSN 2623 0331
p-ISSN 3032 1972

Damage to the coal flow breaker plate occurred over a period of two to four weeks, disrupting operational hours for coal production. During 2022-2023, the total time of obstacles hampering coal production at PT Bukit Asam Tarahan port due to damage to the flow break plate is 695 minutes [1]. This damage causes the bulk flow breaker plate arrangement to disappear as can be seen in Figure 2. This also results in faster damage to the vibrating screen, breakdown time and higher production costs.

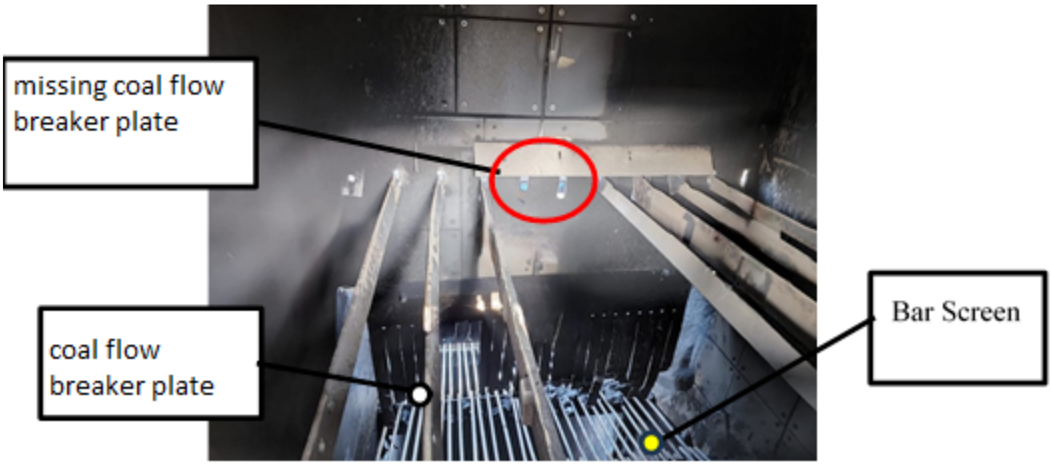


Figure 2. Flow Breaker Plate [1]

The impact load acting on the coal flow breaker plate of vibrating screen is different from the impact load on machines and structures in general. The impact load on the coal flow breaker is the bulk load (falling load) of coal which acts fluctuatingly and continuously and causes failure to the plate. This is an operational problem at PT Bukit Asam Tarahan Port in the shipping process. Based on this problem, the authors has conducted research on the failure of coal flow breaker plates due to impact loads to find the maximum stress and displacement with the aim of extending the operational lifetime of the plate.

Impact loading

Operational loads acting on machines and structures can be classified as static and dynamic loads, depending on whether they remain constant or vary with time. A static load is applied slowly so as not to cause vibrations or dynamic effects on the structure. The load increases slowly from zero to the maximum value and then the load remains constant.

Dynamic loads come in many forms – some loads act and disappear instantly (impact loads), other loads are loads that exist for long periods of time and their magnitude changes continuously (fluctuating loads). Impact loads are generated when two objects collide or when a falling object hits a structure. Fluctuating loads are generated by rotating machines, traffic, wind gusts, water waves, earthquakes, and manufacturing processes.

The response of a structure to falling loads is very complicated, and a complete and accurate analysis requires advanced engineering mathematics. By using the concept of strain energy and making several simplifying assumptions, Gere and Goodno [2] have derived equations for maximum elongation and maximum stress in bars due to axially falling loads.

Maximum elongation

The maximum elongation of rod δ_{max} can be obtained from the law of conservation of energy by equating the potential energy lost due to the falling mass with the strain energy that occurs in the rod, expressed in equation (1):

$$W\left(h+\delta_{max}\right)=\frac{EA\delta_{max}^{2}}{2L} \tag{1}$$

Equation (1) is a quadratic equation in δ_{max} and can be solved to get the positive root as in equation (2)

$$\delta_{max}=\frac{WL}{EA}+\sqrt{\left(\frac{WL}{EA}\right)^{2}+2h\frac{WL}{EA}} \tag{2}$$

Equation (2) can be written in a simpler form by introducing the following notation:

e-ISSN 2623 0331
p-ISSN 3032 1972

$$\delta_{st} = \frac{WL}{EA} = \frac{MgL}{EA} \tag{3}$$

where δ_{st} is the elongation of the rod due to the weight of the load under static loading conditions. Equation (2) can be further written as

$$\delta_{\max} = \delta_{st} + \sqrt{\delta_{st}^2 + 2h\delta_{st}} \tag{4}$$

or

$$\delta_{\max} = \delta_{st}\left[1 + \sqrt{1 + \frac{2h}{\delta_{st}}}\right] \tag{5}$$

Although equation (5) was derived for prismatic rods with axial loads, this equation can be used for other structures with linear elastic properties under falling loads, as long as the stiffness of the structure can be known [2]. Equation (5) can therefore be used for the coal flow breaker plate by substituting the structural stiffness value (fixed-end beam) with appropriate loading condition for the axial stiffness of the rod, *EA/L.*

Maximumt Stress

The maximum stress can be calculated from the maximum elongation with the assumption that the stress distribution is uniform along the length of the bar. From the following equation

$$\delta = \frac{PL}{EA} = \frac{\sigma L}{E}$$

Maximum stress is then

$$\sigma_{\max} = \frac{E\delta_{mx}}{L} \tag{6}$$

Substituting δ_{max} from equation (2) the following equation is obtained for maximum stress

$$\sigma_{\max} = \frac{W}{A} + \sqrt{\left(\frac{W}{A}\right)^2 + \frac{2WhE}{AL}} \tag{7}$$

Define a notation

$$\sigma_{st} = \frac{W}{A} = \frac{Mg}{A} = \frac{E\delta_{st}}{E} \tag{8}$$

where σ_{st} is the stress when the load works statically, equation (8) then becomes

$$\sigma_{\max} = \sigma_{st} + \sqrt{\sigma_{st}^2 + \frac{2hE}{L}\sigma_{st}} \tag{9}$$

or

$$\sigma_{\max} = \sigma_{st}\left[1 + \sqrt{1 + \frac{2hE}{L\sigma_{st}}}\right] \tag{10}$$

Equation (10) is analogous to equation (5) and shows that impact loads produce stress that is greater than the stress if the load acts statically.

The maximum stress on the coal flow breaker plate due to the impact load of falling coal can be determined from equation (10) by substituting for static bending stress which is calculated using a well-known bending formula,

$$\sigma_{bs} = \frac{M_{\max}c}{I} = \frac{M_{\max}}{S} \tag{11}$$

where, S is section modulus, mm^3

There is limited published studies on impact resistance of fixed beam of thin plate. Al-Rifaie et al [3] reported the result of nonlinaer three-dimnsional finite element analysis of impact resistance of I-beam with rectangular web opening. Aliyu [4] investigated the response of steel beams under impact loads by using the energy principles in assessing the capacity of the steel beam to absorb impact energy in deflecting before fracture. The impact loads were as a result of concrete cubes of specific weights of 500 kg, 1 tonne, and 2 tonne dropped from the heights of 15m, 20m, and 2m respectively. The steel beam which was 30 m long was impacted at the quarter span and mid-spans. Tanlak et al [5] carried out shape optimization of box-shaped bumper beam mounted on a vehicle by simulating crash phenomenon using explicit finite element method. To the best of authors knowledge there is no a specific study published in current literature about impact resistance of fixed end beam of thin plate subjected to continuous impact loading. This paper present the result of finite element analysis on maximum stress and displacement of fixed end beam (coal flow breaker plate) using explisite dynamics.

e-ISSN 2623 0331
p-ISSN 3032 1972

FINITE ELEMENT METHOD

This research was carried out using finite element method. For this purpose, ANSYS Workbench 2022 R1 was used with a combination of Explicit Dynamic and Static Structural. With this method, four types of plate materials were simulated. Each type of material was simulated for two different geometries in plate thickness (width as a beam). Table 1 presents the number of data collections of eight, two for each type of material. The simulation results parameters that can be taken are total deformation, stress (von Mises), number of cycles and safety factor. The results of this simulation are used to determine the strongest available type of material to withstand the impact force of coal pouring and increase the service lifetime of the flow breaker plate in the vibrating screen unit.

Tabel 1. Material and dimension of flow breaker plate

Material type	**Impact Force (N)**	***l* (mm)**	***b* (mm)**	***h* (mm)**	**Deformation (mm)**	**σ (MPa)**	**Number of cycles (*n*)**	**Safety Factor**
ST37		1500	15	200				
		1500	20	200				
ST52		1500	15	200				
		1500	20	200				
Hardock (HB400)		1500	15	200				
		1500	20	200				
GS20 Mns		1500	15	200				
		1500	20	200				

Plate geometry and loads are obtained by direct measurements in the field, at PT. Bukit Asam Tbk Tarahan Port Bandar Lampung, precisely at the Unit CV507 (Figure 3). Simulations using the finite element method were carried out at the Structural Mechanics Laboratory, Department of Mechanical Engineering, University of Lampung.

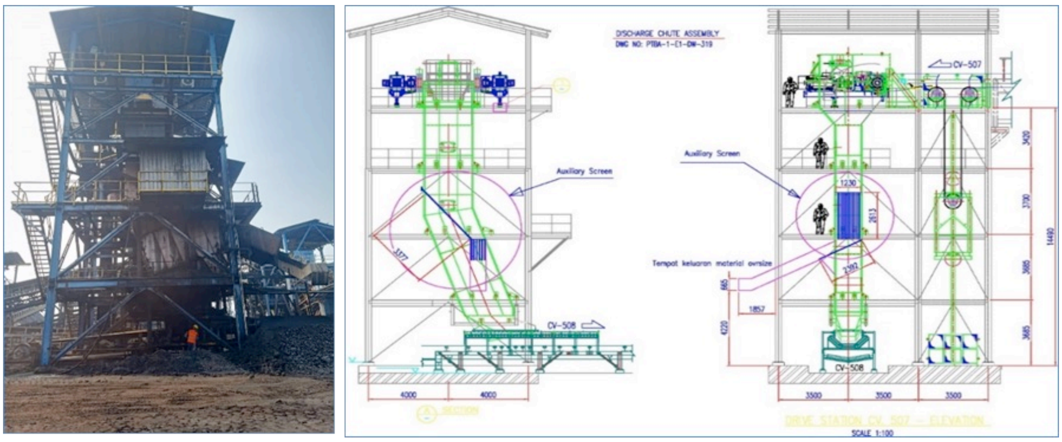


Figure 3. Unit CV507 PT Bukit Asam Pelabuhan Tarahan

PROSIDING SNTTM XXII 2024
Volume 22, Tahun 2024, 02 Oktober 2024
e-ISSN 2623 0331
p-ISSN 3032 1972

Finite Element Procedures

The stages in carrying out a simulation using ANSYS Explicit Dynamic and Static Structural consist of seven stages: as shown in Figure 4. In general, the simulation procedure using ANSYS Explicit Dynamic and Static Structural is as follows:

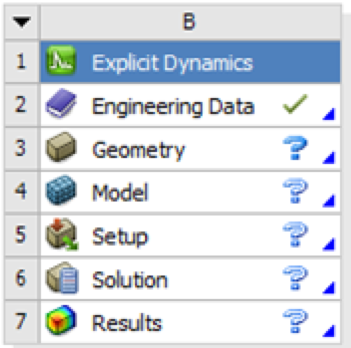


Figure 4. Stages in Finite Element Method using *ANSYS Explicit Dynamic* and *Static Structural*

- **Analysis type**: at this stage the Explicit Dynamic and Static Structural analysis types are selected
- **Material properties**. At this stage, the material properties that will be used in the analysis are determined, including stiffness, strength, and material life characteristics.
- **Geometry modeling**. At this stage the geometry of the structure or system to be analyzed is modeled. This involves creating mesh elements that represent physical geometry
- **Finite element modeling**. At this stage the parameters of the meshing size and contact area for the impact load are determined.
- **Analysis setup**. At this stage, the plane for the fixed support, the plane for the impact load, the impact load value, the simulation time and the time step are determined.
- **Simulation and review of results**. At this stage the simulation is run, and the results are reviewed to analyze the structure's response to the given loads and boundary conditions. The results reviewed are deformation, stress, fatigue life, and safety factors.

Engineering Data

The materials used in this research are ST37, ST52, GS20Mn, and Hardock 400. The mechanical properties of these materials can be seen in Table 2

Geometry

The geometry and dimensions of the coal flow breaker plate are shown in Figure 5. The plate has length l, thickness (width as a beam) t and height h. The plate sizes are given in Table 2.

Table 2. Mechanical properties of plates materials

No.	Material	Poisson's Ratio	Young Modulus (MPa)	Density (kg/m^3)
1	ST37	0.32	210,000	7850
2	ST52	0.30	210,000	8030
3	Hardock 400	0.29	210,000	7473
4	GS 20 Mn5	0.29	190,000	7820

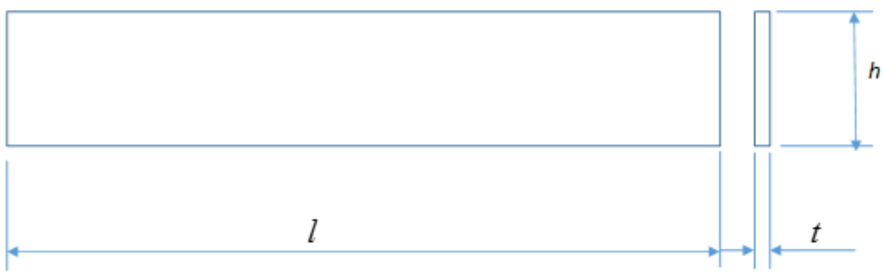


Figure 5. Dimension of coal flow breaker plat

e-ISSN 2623 0331
p-ISSN 3032 1972

Analisis set-up

In this section, the position of the impact load of falling coal on the top side of the beam plate is determined. The load was simulated as a distributed force acting on one third of span of the beam at the middle. Initial conditions, fixed support, and load are also set at this stage. The load value was determined from impact load analysis taken from direct measurements in the field by installing a load cell on the flow breaker plate, the results of which can be seen in Figure.

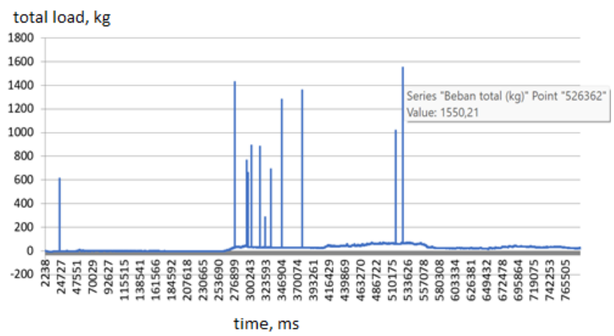


Figure 6. Load measurement of coal fall on flow breaker plate of Unit CV507 Vibrating Screen (courtecy of PT Bukit Asam Tbk., Bandar Lampung)

From Figure 6, it can be seen that the maximum impact load acting on the flow breaker plate occurs at t = 526,362 ms with a value of 1550.21 kg. This load was further simulated as an equivalent distributed load (pressure = 50.63 MPa) on the top surface at one third of the beam length. After all data has been input, starting from initial conditions, fixed support, impact load area, and pressure load values, loading and boundary conditions can be shown as in Figure 7.

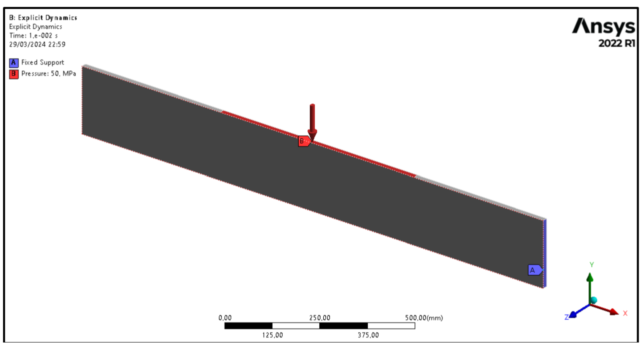


Figure 7. Modeling of load and boundary conditions

RESULTS anS DISCUSSION

Result is the final stage of completing ANSYS Explicit Dynamic and Static Structural. The simulation results presented here are maximum stresses and total deformations.

Maximum stress

Figure 8 shows the stress (MPa) versus time (milli second) curve for the four types of material with two thickness values for each material. Thus there are eight curves in Figure 8. By closely observing each curve line in Figure 8, the maximum stresses value for each material are given in Table 3.

The coal fall on the flow breaker plate (Figure 9b) is modeled and simulated as an impact load evenly distributed over one third of the beam length in the middle with both ends fixed, as in Figure 9a. The maximum stress can be determined from equations (10) and (11). For the beam shown in Figure 9a, the maximum bending moment in equation (11) is determined from equation (12):

$$M_A = M_B = \frac{qb\left(3L^2 - b^2\right)}{24L} \qquad (12)$$

Referring to Figure 9 with the values of a = 0.45m, b = 0.6m, L = 1.5m, and coal fall height h = 5m, the results of stress calculations using equations (10) and (11) agree with the stress in Table 7 within 93 per cent.

With an impact load of 25 kN/m and coal fall height of 5 meters above the vibration screen, Table 3 shows that the ST37 material with a thickness of 20mm is the strongest to withstand the impact load compared to the other three types of material, characterized by the smallest maximum stress value.

Maximum deflection

Figure 10 shows a graph of displacement versus time due to the impact load of falling coal on the flow breaker plate. By closely observing the graph in Figure 10, the maximum deflection for each plate material is recorded in Table 4. With the modeled impact load acting as shown in Figure 9, it can be read from Table 4 that the plate with ST52 material and a thickness of 20 mm has the highest stiffness value compared to the other three materials with the same thickness indicated by having smallest deflection. From Table 2 it is known that the ST52 material has a lower Poisson's ratio and higher density than the ST37 plate material.

e-ISSN 2623 0331
p-ISSN 3032 1972

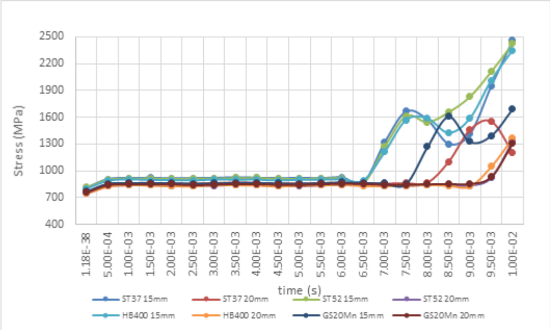
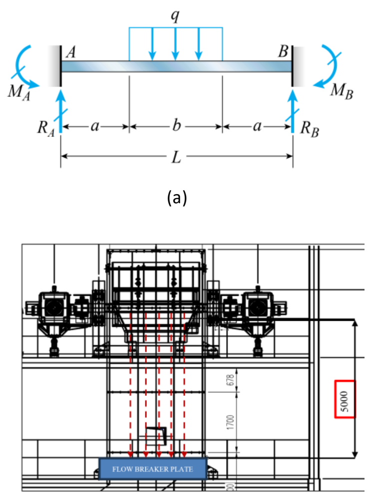


Figure 8. Stress vs. time curve for coal flow breaker plate due to impact loading

Table 3. Maximum stress for due to impact load

Types of material	Dimensions			σ_{max} (MPa)
	l (mm)	b (mm)	h (mm)	
ST37	1500	15	200	2463.1
	1500	20	200	1209.5
ST52	1500	15	200	2424.3
	1500	20	200	1333.2
Hardock (HB400)	1500	15	200	2348.3
	1500	20	200	1543.3
GS 20 Mns	1500	15	200	1694.9
	1500	20	200	1306.9



(a)

(b)

Figure 9. Impact loading on coal flow breajer plate

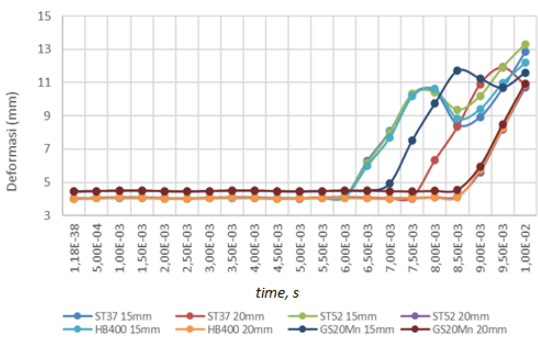


Figure 10. Deformation vs. time curve for flow breaker plate due to impact loading

Table 4. Maximum displacement of flow breaker plate due to impact loading

Type of material	Dimensions			Maximum displacement (mm)
	l (mm)	b (mm)	h (mm)	
ST37	1500	15	200	12.850
	1500	20	200	10.884
ST52	1500	15	200	13.305
	1500	20	200	10.693
Hardock (HB400)	1500	15	200	12.193
	1500	20	200	11.476
GS 20 Mns	1500	15	200	11.586
	1500	20	200	10.942

Theoretically, the maximum deflection due to impact loads can be determined using equation (5). For loading as modeled in Figure 9, static deflection can be calculated using the moment area method from the bending moment diagram. Hadi [1] in his master's thesis shows that the deflection in Table 4 agrees with the theoretical calculation results from equation (5) with a difference of less than 1.2 per cent.

CONCLUSION

From the study of the maximum stress and deflection due to the impact load of coal pouring from a height of 5m on flow breaker plates constructed as beams with fixed ends, the following conclusions can be drawn:

Plates with ST37 material and a thickness of 20 mm are the strongest material to withstand impact loads compared to the other three types of material.

Plates with ST52 material and a thickness of 20 mm have the best stiffness compared to the other three types of material

ANSYS Explicit Dynamic can be used to evaluate the strength of plate beams under impact load.

ACKNOWLEDGMENT

The authors are very grateful to the Faculty of Engineering, University of Lampung for funding this research in DIPA FT 2024 under contract number 2107/UN26.15/LK.03/2024. High gratitude goes to PT Bukit Asam Tbk., Tarahan Port Bandar Lampung for giving access to the CV507 vibrating screen within the company.

REFERENCES

[1]. K.A. Hadi, Analisis kegagalan fatigue impact untuk memaksimalkan lifetime plat pemecah aliran batubara pada screen CV507 PT Bukit Asam Pelabuhan Tarahan. Graduate (Master) Thesis (2024), Department of Mechanical

e-ISSN 2623 0331
p-ISSN 3032 1972

Engineering, University of Lampung.

[2]. J.G. Gere, and B.J. Goodno, Mechanics of Materials, 8th Edition (2013). Cengage Learning, Stamford, USA.

[3]. A.Al-Rifaie, A.S. Al-Husainy, T. Al-Mansoori, A. Shubbar, Flexural Impact Resistance of Steel Beams with Rectangular Web Opening. Case Studies in Construction Materials. 14 (2021) 146.

[4]. O.H. Aliyu, Design Recommendation for Steel Beam Subjected to Impct Load to Prevent Brittle Fracture. Nigerian Journal of Technological Development, Vol. 16 No.2 (2019) 78 – 84.

[5]. N. Tanlak, F.O. Sonmez, and M. Senaltun, Shape optimization of bumper beams under high-velocity impact loads. Engineering Structures, 95 (2015) 49 – 60