

# Development of a New Generation High Crushing Capacity Jaw Crusher with an Automatically Adjusted Closed Side Settings

<sup>1</sup>Ozge Guler, <sup>2</sup>Mustafa Cemal Cakir,

<sup>1</sup> Burçelik A.Ş., <https://orcid.org/0000-0003-4076-1624>, [ozge.guler@burcelik.com.tr](mailto:ozge.guler@burcelik.com.tr)

<sup>2</sup> Uludag University, <https://orcid.org/0000-0003-0816-4029>, [cemal@uludag.edu.tr](mailto:cemal@uludag.edu.tr),

\* Corresponding author: [ozge.guler@burcelik.com.tr](mailto:ozge.guler@burcelik.com.tr)

(First received September 06, 2023 and in final form December 24, 2023)

**Reference:** Guler, O., Cakir, M., C. Development of a New Generation High Crushing Capacity Jaw Crusher with an Automatically Adjusted Closed Side Settings. The European Journal of Research and Development, 3(4), 161-177.

## Abstract

*The design and development of a new generation high crushing capacity jaw crusher, developed for the first time in Turkey and whose Closed Side Settings (CSS) may be automatically adjusted hydraulically, were investigated in this study. The calculations for the crusher developed for this purpose were included in the paper. The design modifications made to expand the crusher's jaw stroke from 27 mm to 40 mm were documented, and the capacity increase resulting from this was theoretically calculated and proven by a wide range of field tests conducted after the jaw crusher was manufactured. Field testing and their findings were also thoroughly covered in the paper. The forces on the crusher jaw and bearings, the crusher body geometry and crusher material (via fatigue analysis), and the dynamic performance of the system (via vibration analysis of the carrier system) were examined as the outcome of the FEM (Finite Element Method) and DEM (Discrete Element Method) analyses performed after the theoretical calculations. With improvements made based on the findings gained, the theoretical and practical harmony of the created jaw crusher system was realized. Field testing has proven that the adjustment procedure takes no more than 3 minutes and requires no human participation. As a result of this research, a patent application for the created automation algorithm was filed.*

**Keywords:** Jaw Crusher, Trajectory Analysis, Closed Side Settings

## 1. Introduction

Aggregate is a pile of unbroken and/or crushed grains of natural, artificial, or both solid mineral material of varying sizes, often ranging from 1.5 m to 0–5 mm. Crushers are industrial machines that conduct size reduction, often known as crushing. Primary crushers are classified into three types: primary jaw crushers, primary impact crushers, and gyrator crushers. Primary jaw crushers are commonly used as primary crushers in Turkey. These crushers have a speed range of 200–350 rpm [1].

Primary jaw crushers comprise a pitman (mobile jaw), a body, and a fixed jaw. By exerting just pressure or cutting and abrasion with pressure through the elliptical movement of the pitman, jaw crushers compress and break the material supplied from the top between the fixed and moving jaws. As the pitman moves away from the fixed jaw, the size reduction process of the material is accomplished, and it is discharged from the opening between the jaws at the bottom.

Depending on the material size and capacity expected from the jaw crusher at the end of the crushing process, the piston movement can be adjusted by pushing the adjustment block and toggle plate closer or further away from the fixed jaw. This arrangement is known as CSS (Closed Side Settings) in the context of manufacturing. Adjustments to the CSS are required to modify the size and capacity of the product getting out of the crusher (Figure 1). The springs and toggle plate give the pitman eccentric orbital back and forth movement balance and the crusher closed side is kept constant during the crushing operation. Jaw crushers can be separated into two categories based on the movement mechanism of the moving jaw: single toggle jaw crushers and double toggle jaw crushers. In the aggregate sector, single toggle jaw crushers (Figure 2) are often preferred. Within the scope of the study, an innovation on the single toggle jaw crusher was developed.

The main drawbacks of jaw crushers are their low crushing capacity and extended CSS duration. Unlike current jaw crushers, the amount of eccentricity and pitman angle were estimated within the scope of this study, the capacity of the jaw crusher was increased, and the construction of a new generation jaw crusher with automatically adjustable CSS was considered.

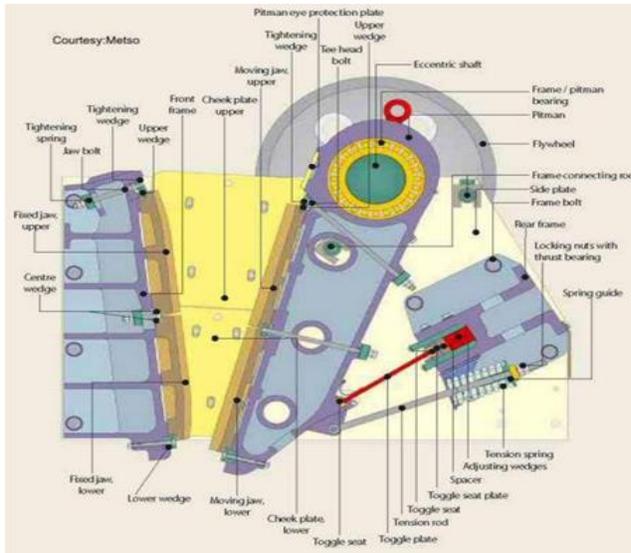


Figure 1: Components of a jaw crusher [1]

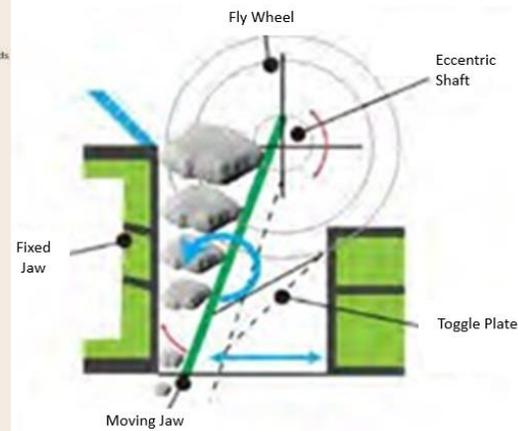


Figure 2: Single toggle jaw crushers [2]

Jaw crushers built in Turkey have crushing capacities ranging from 250 to 700 tons per hour. However, the objective of this endeavor was to design and fabricate a jaw crusher capable of producing between 350 and 900 tons per hour. Turkey is to be home to producers capable of producing jaw crushers with hydraulic systems that control CSS. Nevertheless, they establish the CSS's tension via a spring mechanism and adjust this configuration with shims in response to operator input. This condition lengthens the adjusting period and is at the discretion of the operator. An innovative aspect of this investigation is that the CSS and pretension adjustments of the jaw crusher are performed automatically in the present study.

Ozcan et al. [3] were observed to have conducted comprehensive sampling studies in order to evaluate and optimize the performance of crushing and screening facilities. As a result of the study's evaluation of crusher performance, it has been observed that an increase in the reduction rate of the crusher occurs with a decrease in the fine material supplied to the crusher at an intensive rate, while a decrease in the crusher CSS leads to an increase in the reduction rate of the crusher. In his study, Arman [4] investigated the fundamental operating principles, criteria for selection, and considerations that must be made in the implementation of crushing, screening, and conveying machinery. The research encompasses computations of the engine power necessary to fracture materials at specific capacities for a range of stones by employing the work index. In their study, Deepak (5) investigated the correlation between the crushing performance and the kinematic properties of the jaw crusher. They analyzed force distributions, crushing parameters, and the kinematic properties of specific locations along the jaw plate, in

addition to kinematic calculations of jaw crushers. His research led him to the conclusion that the forces exerted in the crushing chamber throughout the process of crushing vary depending on the region of the jaw involved. Deriving the position, velocity, and acceleration equations of any given point of the jaw crusher was of interest to Oduori et al. [6]. The researchers reached the conclusion that the toggle plate configuration of the single toggle jaw crusher could be represented in a planar kinematic model as a consequence of their investigations. During the crushing process, Garnaik [7] investigated the kinematics, flywheel energy, and spring calculations of the jaw crusher. The main parameters pertaining to the movement characteristic value of the movable jaw of the jaw crusher were acquired by Zhang et al. [8] through the utilization of virtual prototype technology and the orthogonal testing method. It was determined that the oscillation angle is the most crucial parameter. In their investigation, Fusheng et al. [9] developed discrete element method models for a double-cavity jaw crusher in order to assess the force condition and crushing power of the tooth plate. Consequently, an analysis was conducted on the crushing process of spherical particulates in the crusher, including the force exerted on the teeth and the crushing power. Guan et al. [10] developed a simulation model and conducted dynamic analyses in order to enhance the jaw crusher's design. Legendre et al. [11] investigated the causes of jaw crushers' limited productivity. The electrical power values were recorded and documented throughout the experimental crushing procedure involving around 600 g of aggregate. The results indicated that breakdown had a detrimental effect on energy efficiency, amounting to 10%.

When national and international patents were investigated as part of the research, the connection of the flywheel and pulley sections of a jaw crusher with a tightening nut, thereby allowing ease of installation and maintenance of the jaw crusher, was explored in the [TPE 2012/02118] patent. [WO 2013/167393] is concerned with the creation of CSS in a jaw crusher using a shim plate, a hydraulic cylinder, and hydraulic equipment, whereas [WO 2013/167393] is concerned with the application of angular force by a hydraulic piston to the CSS of a jaw crusher. [CN 11226417,8A] describes an automated control approach for jaw crushers. This crusher has a data gathering device that measures the raw material level, rotating speed, and pump pressure. [WO 202001340,6A,1] provides a method and system for measuring the size of the exiting material in jaw or cone crushers in real time, warning the operator, and allowing the crusher to be adjusted.

## 2. Material and Method

The subsequent procedures were adhered to in the course of this research:

- Conducting an analytical analysis of the trajectory of the developed jaw crusher and calculating the crushing capacity per unit time by quantifying the x-direction movement of the moving jaw,
- Formulating kinematic position, velocity, and acceleration equations for the jaw crusher under development, followed by force analysis and CAD data generation for the crusher;
- Employing the finite element method to conduct stress analysis on various components of the new generation jaw crusher, including the camshaft, body, fixed jaw, and pitman; fatigue analysis on movable portions of the machine; and vibration analysis of the entire machine.
- Conducting calculations for standard hydraulic machine components, including the hydraulic piston, hydraulic motor, pump, and hydraulic accumulator, utilizing analytical methods.
- Field experiments to validate the design, calculations, design enhancements, and capacity expansion.

### 2.1. Force Analyses, Determination of Trajectory and Crushing Capacity

The four-bar mechanism is employed to ascertain the static analysis and force transmission characteristics of single toggle jaw crushers (Figure 3). The kinematic model of a four-bar mechanism single toggle jaw crusher depicts the eccentricity dimension  $r_2$  rotating at a constant speed around the crank  $O_2$ . The Pitman-length  $r_3$  coupler link induces elliptical motion at each point.  $r_4$  denotes the extent of the toggle plate.

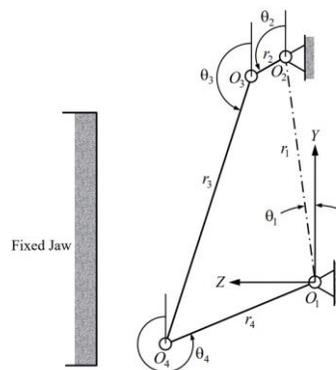


Figure 3: The kinematic model of a four-bar mechanism single toggle jaw crusher [1]

The forces and force transmission ratios, as well as movement analysis of any point on the pitman during operation, were ascertained with the assistance of an Excel file developed for the crusher, whose mechanism values were determined through preliminary design calculation selections. The study utilized  $\theta_3$  and  $\theta_4$ , which corresponded to each value of  $\theta_2$ . The Freudenstein equation was utilized to calculate orbits [2].

Stroke is defined as the difference between the furthest point and the closest point of the movable jaw to the fixed jaw at the jaw crusher outlet. When calculating the capacity of a jaw crusher, the amount of stroke is the most critical factor.

$L_{MAX}$ : Opened Side Setting (OSS)

$L_{MIN}$ : Closed Side Setting (CSS)

$L_T$ : x-direction movement of pitman (*Stroke*)

$$L_T = L_{MAX} - L_{MIN} \quad (1)$$

The primary objective of the study was to ascertain the stroke necessary to increase the capacity, assuming all other physical body dimensions remained unchanged. To attain the desired capacity value, a decision was made to increase the stroke from 27 mm to 40 mm (Figure 4). The critical and optimal speeds for this enhancement were identified.

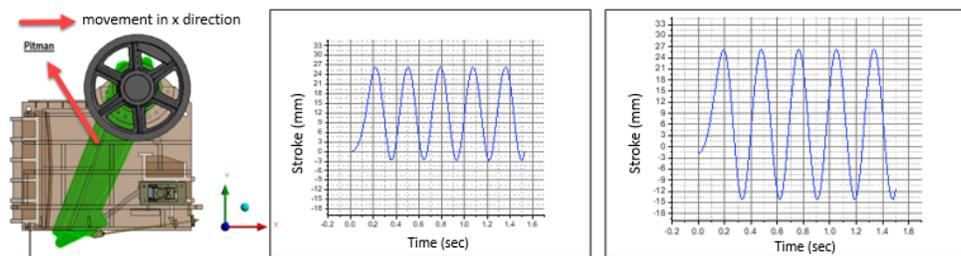


Figure 4: x-axis movement of the pitman for two distinct configurations

As a result of their work together with crusher manufacturers, Rose and English [12] and Kelly and Spottishwood [13] defined the optimum speed at which the crusher should operate according to the crusher inlet width  $G$  (Gape). In this study, the optimum operating speed was calculated as approximately 168-252 rpm.

$$n_{OPT} = 280 \exp(-0.212 G^3) \pm 20 \% \quad (2)$$

Rose and English made the observation that the capacity exhibits an increase until a specific threshold is reached in relation to the number of strokes per minute. Beyond that

threshold, the capacity decreases. Due to this rationale, the critical speed of the crusher assumes significance when calculating the utmost capacity. The calculations determined the critical speed to be 210 revolutions per minute.

$$n_c = 47 \frac{1}{(L_T)^{0.5}} \left( \frac{R-1}{R} \right) \quad (3)$$

A range of empirical formulas are employed in the calculation of capacity for jaw crushers. The formulas most frequently employed in this context are those of Rose and English [12], Michaelson [14], Hersam [15], and Broman [16]. The Rose and English formula yielded the most accurate results in relation to the actual capacity compared to the other formulas.

$$Q_M = 2820 L_T^{0.5} W (2 L_{MIN} + L_T) \left( \frac{R}{R-1} \right)^{0.5} \rho_S f(P_K) f(\beta) S_C \quad (4)$$

$Q_M$ : maximum capacity at critical velocity (yüksek strok sayısında),  $m^3/h$

$L_T$ : stroke, m

$W$ : width of jaw plates, m

$L_{MIN}$ : closed set, m

$R$ : machine reduction ratio,  $R = G/L_{MIN}$

$\rho_S$ : solid density,  $t/m^3$

$f(P_K)$ : parameter of size distribution function,

$f(\beta)$ : parameter of related this to the set opening and the mean size of the particles,

$S_C$ : parameter related to the surface characteristics,

The parameters of the function are in [2] reference.

Table 1 provides the current values for jaw crushers; the density is assumed to be  $1.6 t/m^3$ . Table 2 illustrates the capacity increase that results from raising the stroke by 13 mm.

Table 1. Calculated and collected capacity values from the field

CSS (mm)	Capacity (from the field) (t/h)	Capacity (calculation by Rose&English)(t/h)
150	280-320	288-328
200	350-400	397-440
280	470-540	590-638
350	550-650	683-728

Table 2. Current status of capacity

CSS (mm)	Capacity (t/h)
150	370-395
200	519-541
280	744-812
350	961-1096

The required engine power requirement of the developed jaw crusher was found to be approximately 185 KW.

$$P_{MAX} \text{ (kW)} = 67.4 w W_i L_T^{0.5} \left( L_{MIN} + \frac{L_T}{2} \right) \left( \frac{R}{R-1} \right)^{0.5} \rho_s \left[ \frac{\sqrt{G}-1.054 \sqrt{(L_{MIN}+L_T)}}{\sqrt{G} \sqrt{(L_{MIN}-L_T)}} \right] f(P_K) f(\beta) S_C \quad (5)$$

$P_{MAX}$  : maximum required power, kW

$L_T$ : Stroke, m

$W$ : width of jaw plates, m

$W_i$ : working indeksi, kWh/t

$L_{MIN}$ : closed set, m

$\rho_s$ : solid density,  $t/m^3$

$R$ : machine reduction ratio,  $R= G/L_{MIN}$

$G$ : gape, m

$f(P_K)$ : parameter of size distribution function,

$f(\beta)$ : parameter of related this to the set opening and the mean size of the particles,

$S_C$ : The coefficient dependent upon the surface characteristics of the material.

Using the Bonwetsch [17] formula, the maximum chrushing force exerted on the pitman was calculated; the four-bar mechanism yielded the maximum force ( $F_{MAX}$ ) value of 3707 kN.

$$F_{MAX} = 123000 \frac{P}{r n} \quad (6)$$

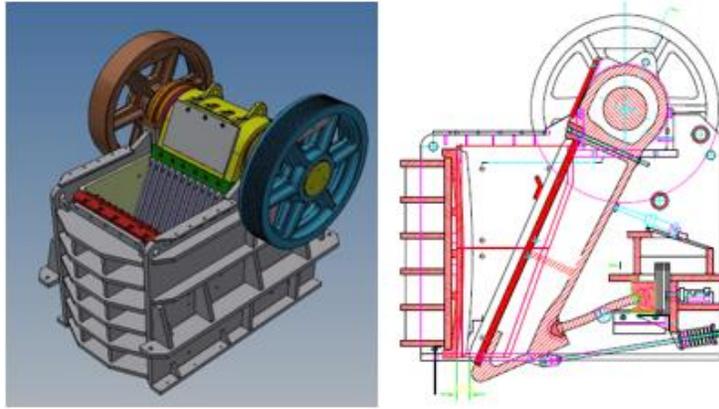
$F_{MAX}$ : Maximum crushing force, kN

$P$ : motor power, kW

$r$ : eccentricity in the spindle, mm

$n$ : rotational speed, rpm

During the crushing operation, the primary function of the support plate in jaw crushers is to transfer the majority of the crushing load to the main body. Utilizing the movement acquired from the wedge adjustment block, to which it is connected, in the crusher outlet, is an additional critical task. To ascertain the location and dimensions of the support plate, it is necessary to analyze the force acting on the arm  $r_4$ . The force applied to the support plate was determined to be 4231 kN using the Bonwetsch [17] formula and four-bar force analysis. Following the determination of stroke value and trajectory analysis for the developed jaw crusher, kinematic position, velocity, and acceleration equations were derived. Subsequently, the force analysis was utilized to generate the CAD model of the system (Figure 5).



Şekil 5: Çeneli kırıcının CAD Datası

In the study, two distinct design improvements were implemented. Investigations were conducted on four-bar mechanisms in an effort to increase the stroke, which in the current design was 27 mm. It was determined that the toggle plate in the new design could not be positioned higher. The toggle plate was appropriately positioned within the four-bar mechanism for the 40 mm stroke, and the ultimate design was developed subsequent to the calculation of the force value (Figure 6). The hydraulic wedge system (Figure 7) was first angled in the initial design but was subsequently repositioned horizontally in the final design, enabling automatic adjustment.

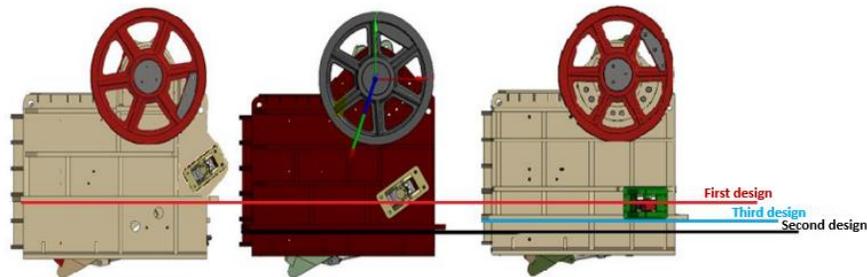


Figure 6. Two distinct improvements

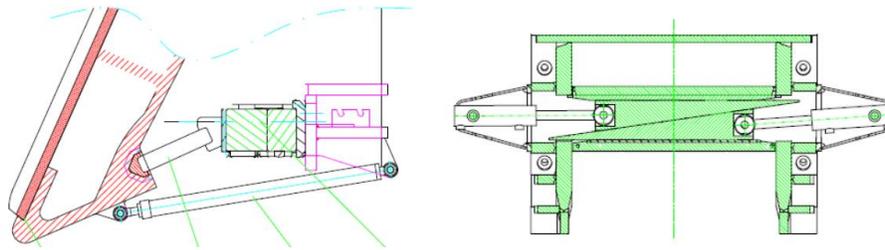


Figure 7. Pitman linkage and hydraulic wedge system in the final design

The wedge hydraulic adjustment system's automatic CSS in a maximum of five minutes without operator intervention is the most innovative aspect of this work. A hydraulic system with two cylinders and a linear ruler attached to one of them will drive the wedge. The CSS amount will be displayed on-screen, and the pistons will move linearly. In contrast to the jaw crusher holder mechanisms utilized in other research, this study employs a spring system as a piston shock absorber. This distinguishes it from other investigations.

In order to regulate the outlet of the crusher, analytical calculations were performed on hydraulic system components, including the hydraulic piston, motor, pump, and hydraulic accumulator, following the completion of the design studies for the jaw crusher. During the hydraulic cylinder calculations, the following values were determined: 7.32 lt/min for the flow rate, 2.2 kW for the electric motor power, 147 kN for thrust, and 101 kN for tensile force. The hydraulic accumulator's pressure and volume are calculated to be within the intervals of 60–67.44 bars and 1.4-1,59 L respectively.

$$Q = \frac{3}{50} Av \quad (7)$$

Q: flow rate, lt/min

A: area, cm<sup>2</sup>

v: speed, cm/s

$$N = \frac{P Q}{600 \rho} \quad (8)$$

P: max pressure, bar

Q: flow rate, lt/min

N: electric motor power, kW

$\rho$ : electric motor efficiency, 0,85-0,9

## 2.2 FEM and DEM Analyses and Improvements

FEM (Finite Elements Method) and DEM (Discrete Elements Method) were employed to analyze the jaw crusher that was optimized for the research. Crushing forces for aggregates of varying diameters in the jaw were ascertained with the assistance of DEM (Figure 8). FEM was utilized to determine forces acting specifically on the jaw crusher body and bearings (Figure 9). An investigation was conducted on the vibration characteristics of the crusher carrier (Figure 13), the strength of the jaw crusher body (Figure 10), and the state of fatigue of the jaw crusher components (Figure 12). The analytical calculations yielded consistent force values on the pitman in accordance with particle size as represented by the crushing model.

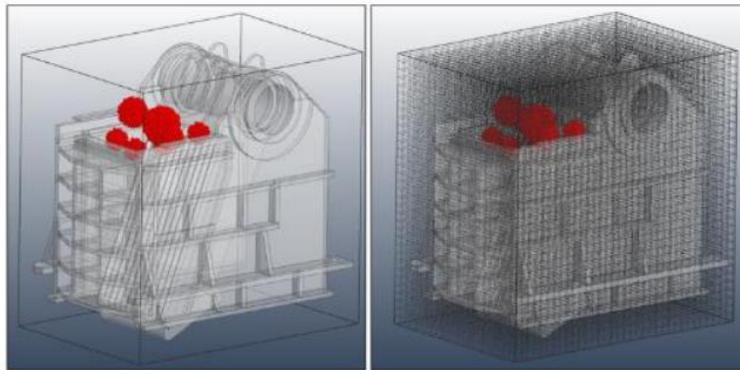


Figure 8. DEM analyses of the jaw crusher

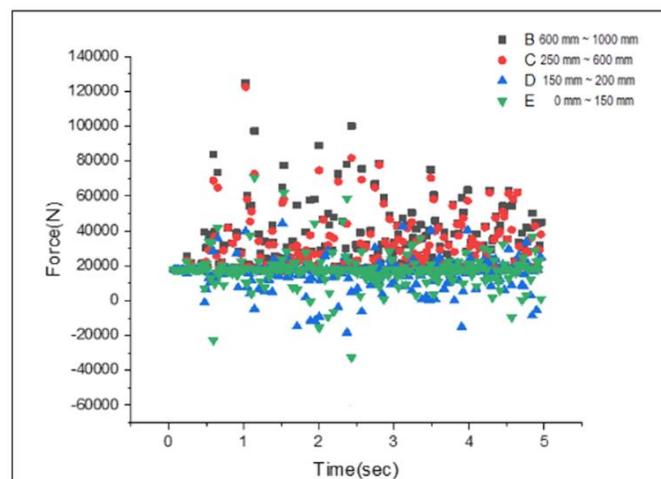


Figure 9. Force values on the pitman in accordance with particle size

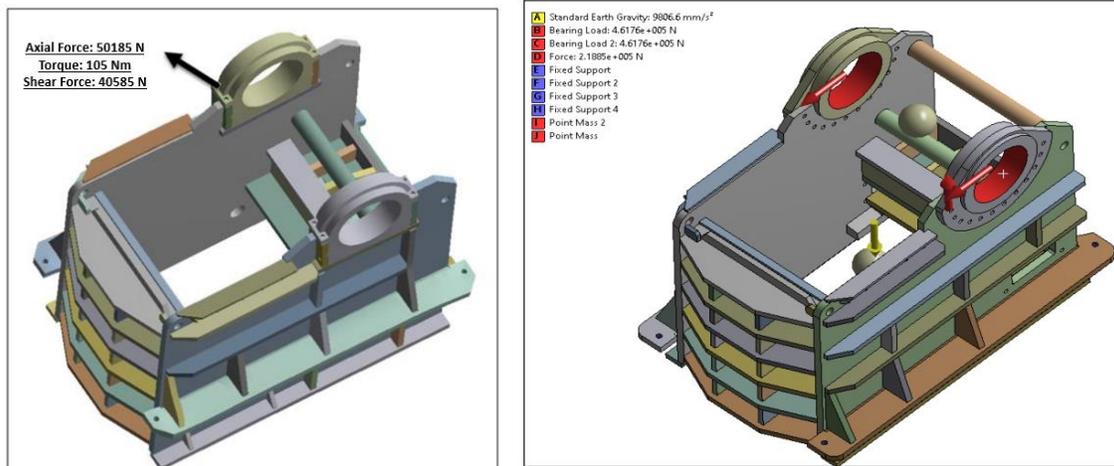


Figure 10. Forces acting on bearings and boundary conditions for the strength of the jaw crusher body

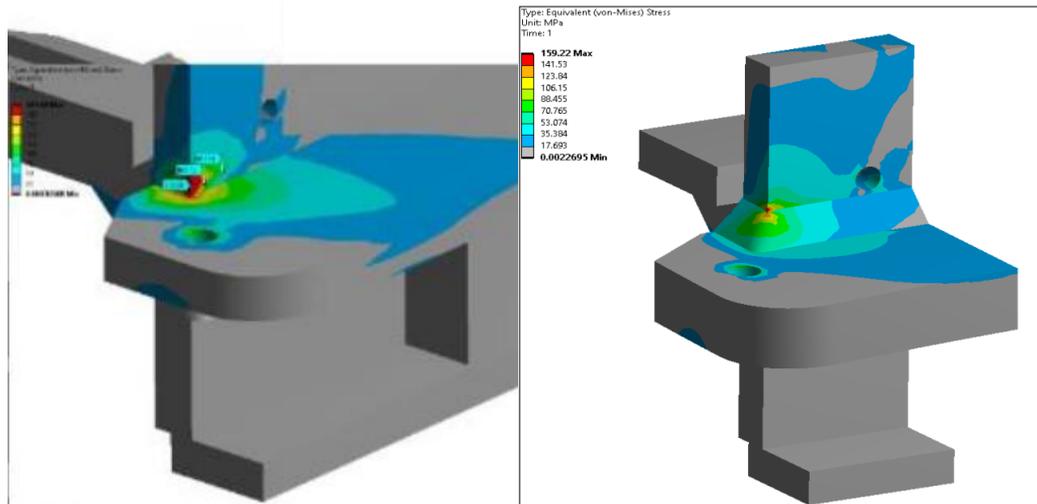


Figure 11. Improved stress distribution due to the improvements of the crusher body

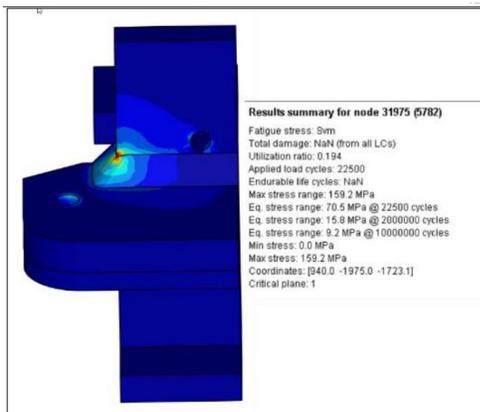


Figure 12. Fatigue analyses  
2.3. Field Tests Performed

Mod	Frekans(Hz)
1	4.4
2	17.76
3	20
4	23.5
5	31.34
6	33.5
7	43.3
8	44
9	52.2
10	52.6

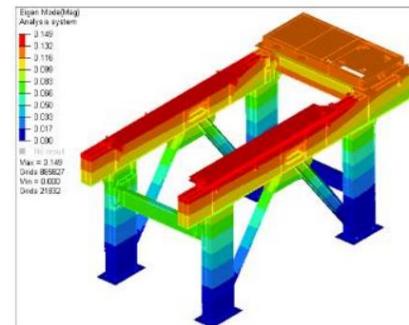


Figure 13. Vibration analyses of the chassis

Upon the conclusion of the prototype manufacturing process for the jaw crusher, the subsequent series of field studies were conducted.

### 2.3.1. No-Load Starting Tests

Following the conclusion of the prototype manufacturing process, the machine was left in a vacant state and the subsequent inspections were conducted.

- a. Screen captures of the investigations conducted to ascertain whether the current value drawn by the motor varies over a minimum of two hours of operation are included in the "Safety and Functionality Tests-Current Control Studies" section.
- b. Throughout the field research, assessments were conducted to identify any impingement noise associated with friction or a comparable mechanical issue when the engine was operating at rest. During the applicable examination, it was noted that there were no indications of mechanical malfunction or commotion associated with friction.

### 2.3.2. Capacity Tests

Trial production was conducted using the developed jaw crusher under authentic operational conditions throughout this assessment (Figure 14). The trial production determined whether the maximum crushing capacity of a specific variety of dolomite stone was 350 tons per hour at a CSS of 150 mm and 900 tons per hour at a CSS of 350 mm. As predicted by the theoretical calculation, increased capacity values were attained. The conducted research involved the loading of 1050 tons of material per hour through a jaw opening of 200 mm and 578 t/h of material through the jaw crusher.



Figure 14: Trial production

The studies conducted as part of the test yielded values of 421 t/h and 1,009 t/h, respectively, when the CSS was at 150 mm and 350 mm. The outcomes of the tests are detailed in Table 3. The task has been effectively concluded.

Table 3: Outcomes of the capacity tests

CSS (mm)	Capacity (t/h)
150	421
200	578
275	797
350	1009

### 2.3.3. Gradation Test

In the context of this test, an assessment was conducted to determine if the stones that underwent crushing by the jaw crusher, which is the focal point of this study, fulfilled the intended criteria for gradation rates.

During the experimental procedure, specimens were extracted from the fragmented stones using the jaw crusher that was specifically designed for this research endeavor. Subsequently, these specimens were subjected to sieving, followed by a study of their grain distribution. The sieve analysis was conducted to determine if the samples obtained from the crushed stones met the requirement of passing a minimum of 95% through the sieves with a width ranging from 150 to 350 mm.

Based on the conducted investigations within the testing framework, it was discovered that the specimens obtained from stones subjected to crushing with a closed side setting (CSS) of 150 mm exhibited a complete passage rate of 100% through wire mesh sieves ranging from 5 to 275 mm. The gradation curve visually represents the results of the sieve study conducted for all particle size ranges inside the CSS. The findings of the experimental trial conducted as part of the research are depicted in Figure 15, indicating the successful completion of the respective tests.

### 2.3.4. CSS (Setup) Test

During the comprehensive CSS test conducted for the jaw crusher under development, an assessment was undertaken to determine the feasibility of achieving a CSS range between a minimum of 150 mm and a maximum of 350 mm. The CSS value inputted using automation during the test was then verified using CSS gauges. In both the organizational setting and during practical application, the CSS was observed to range from a minimum of 150 mm to a maximum of 350 mm. The figures in Figure 16 depict the visual representations of the investigations conducted as part of the test.

Using ten repetitions, it was determined whether the adjustment procedure could be completed in a maximum of five minutes without operator intervention. During the

course of the experiment, it was noted that the adjustment procedure accomplished the utmost completely closed and fully open positions autonomously and in an average of three minutes. The maximum distance travelled is 200 mm and the feed speed is 1.11 mm/s.

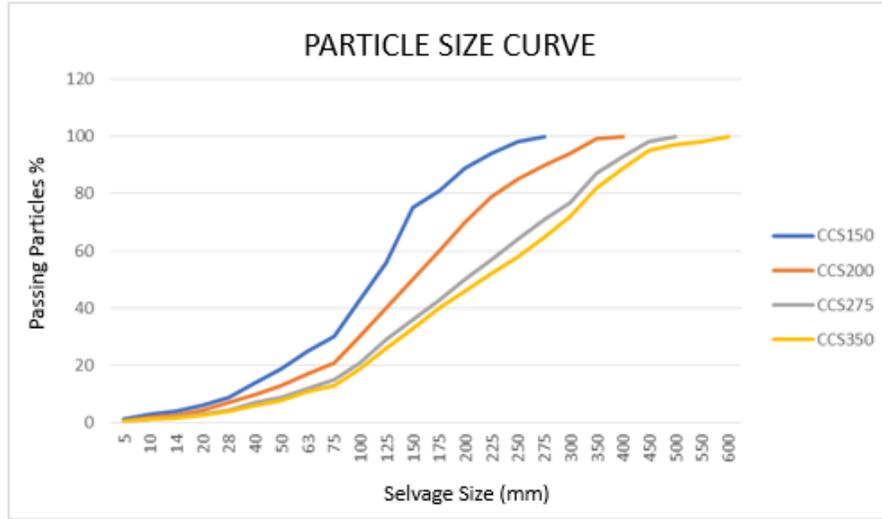


Figure 15. Gradation test results



Figure 16. CSS set up ve control screens

The test activities encompassed an examination of capacity, speed, efficiency, and setup parameters, with a focus on assessing their appropriateness.

### 3. Conclusion

This study investigated the development of a jaw crusher of the next generation high crushing capacity, the first of its kind in Turkey, which, unlike extant jaw crushers, has a hydraulically adjustable jaw aperture. In order to accomplish this, the study provides comprehensive calculations for the developed crusher. Specifically, it details the enhancements implemented and theoretically calculates the capacity increase that results from increasing the jaw x-axis displacement from 27 mm to 40 mm. Post-production tests validate this capacity increase. Static and dynamic verifications pertaining to forces, geometry, and materials were conducted as a consequence of FEM and DEM analyses. The enhancements implemented ensured the developed system's compatibility with both theory and practice.

The study referenced in this article led to the development of an automation algorithm and the filing of a patent application titled "Algorithm of Automation of Jaw Opening Adjustment in Jaw Crushers Compatible with Optical Identification Technology" (application number 2020/03306. TPE 2021/014961 a "A Crusher Supported by Artificial Intelligence" and TPE 2022/019220 "A System and Method Supported by Artificial Intelligence Algorithms to be Used in Mineral and Aggregate Crusher Facilities" are patent applications pertaining to jaw crushers that were developed as part of other R&D activities.

### Acknowledgement

The present investigation was conducted in fulfillment of the TEYDEB 1501 project with the identification number 3191593. We express our gratitude to TÜBİTAK for their assistance.

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