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*Research Article*

# Estimation of the Fatigue Life of Test Specimens Made from Ferrous Metals Using Graphical Technique

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**Abstract:**
*New engineers in mechanical design occasionally encounter difficulty when forecasting the fatigue life of created parts under dynamic conditions. This is because, during the design phase, the size of the pieces is regularly adjusted along with the changing material type, the modified design factor, and even the magnitude of the load in order to generate a prototype that is most compatible with the design circumstances. However, theoretically estimating a part's fatigue life is challenging and time-consuming. Therefore, It might not be the ideal option for the current mechanical design process because it contradicts the QCD paradigm, which is thought to be the cornerstone of industrial production. As a result, this article presents a graphical technique using AutoCAD software to estimate the fatigue life of test specimens made of ferrous metals with ultimate tensile strengths ranging from 490 to 1400 MPa. This approach produces accurate and reliable results when compared to an equation-based fatigue life estimation procedure. This method shortens the time and expense of design. Additionally, as compared to the conventional way, increases the mechanical design's flexibility and agility.*

**Keywords:** *Fatigue life, Ferrous metals, Graphical technique, Endurance limit, High cycle fatigue, Semi-log*

## 1. Introduction

Mechanical design is typically split into two categories: 1. Statics or quasi-statics; 2. Dynamics. The statics section focuses on creating components or systems that can support loads without breaking down. On the other hand, the dynamics section usually concentrates on creating components or systems that can tolerate loads while controlling fatigue.

There will be two groups of interest for the dynamics section: As seen in Fig. 1(a), there are two types of life designs: 1. Finite life, which has a limited lifespan and is used when the number of cycles ($N$) does not exceed 10 million cycles. Currently, if the metal is ferrous, the criterion is typically set at $N$ not exceeding 1 million cycles. 2. Infinite life, which has an unlimited service life and is used when the number of cycles ($N$) is 1 million cycles or more. The two aforementioned groupings further divided the metals under examination into two groups: 1. Ferrous metals, or metals in the iron group, and 2. Nonferrous metals, or metals outside the iron group. The ferrous metals group has an intriguing unique mechanical property known as the endurance limit, which is discovered in infinite life design, according to metallurgical understanding. The nonferrous metals category does not contain this mechanical feature.

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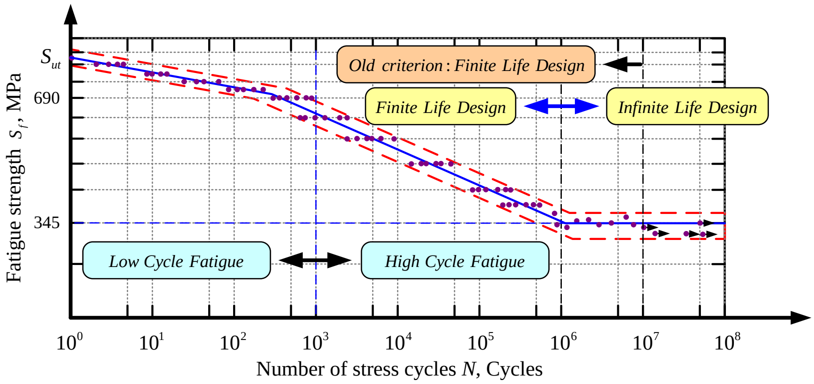
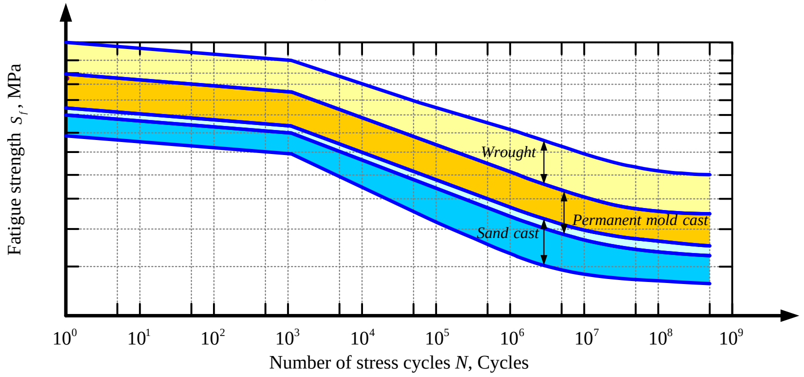
Both types of metals will exhibit fatigue strength or fatigue resistance capabilities, which are evident in finite life design. Fig. 1(a) depicts an *S-N* curve for ferrous metals, while Fig. 1(b) depicts the typical *S-N* curve of a nonferrous metal.

The *S-N* curve is commonly used to analyze fatigue in machines that have dynamic problems. High cycle fatigue (HCF), defined as *N* more than 1000 cycles, will be used as a case study in this article. Thus, this paper will not address the situation where *N* is fewer than 1000 cycles, which is also referred to as low cycle fatigue, or LCF.



(a) Ferrous metals



(b) Nonferrous metals

**Fig. 1.** S-N Curve. [1, 2]

The difficulty and complexity of predicting the fatigue damage of mechanical parts designed under dynamic conditions or the incorrect estimation of the life expectancy of mechanical parts is a major issue that arises every generation for new mechanical designers of design and manufacturing machinery contracting companies. Consequently, the business must spend a significant amount of money on machine maintenance or client replacement spare parts. Maybe because many young designers do not yet have an in-depth comprehension of how materials fatigue. Moreover, there is no linear relationship between the fatigue resistance ($S_f$) behavior of mechanical parts and the number of loading cycles (*N*).

Thus, in order to simplify and lessen the complexity of the estimating process, this article provides a graphical estimate of the fatigue life of test specimens made from ferrous metals using AutoCAD software. It has a respectable degree of accuracy in addition to being more convenient and time-efficient. Not limited to fatigue test specimens, this knowledge can also be applied to future mechanical part designs.

## 2. Variable Load

Six categories are used in [3, 4] to classify the hypotheses on cumulative fatigue damage: 1. Miner's rule or linear damage rules (LDR) 2. Two-stage linearization technique and nonlinear damage curve 3. Techniques for modifying the life curve 4. Methods based on the idea of crack growth 5. Models of continuum damage mechanics; and 6. Theories based on energy.

Numerous investigations and tests on fatigue have been conducted throughout history, leading to the division of fatigue into groups based on the kind of load, including dynamic torque, dynamic axial force, and dynamic bending moment. The dynamic bending moment experiment is the most widely used [2, 5]. Then, an *S*-*N* curve is created using the data about the test specimen's endurance limit ($S'_e$) or fatigue strength ($S'_f$) from the experiment. This curve is employed as crucial information in mechanical design under dynamic problems for various use in the future situations (as shown in Fig.2).

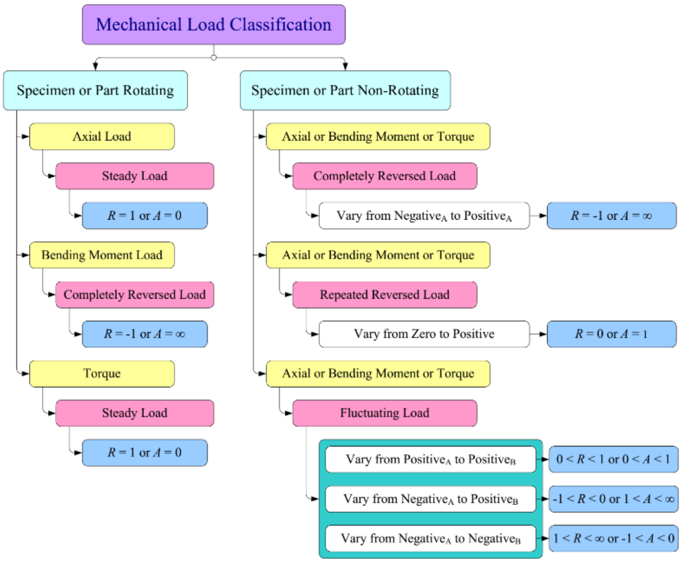
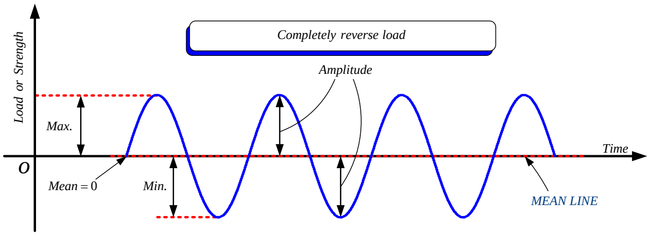
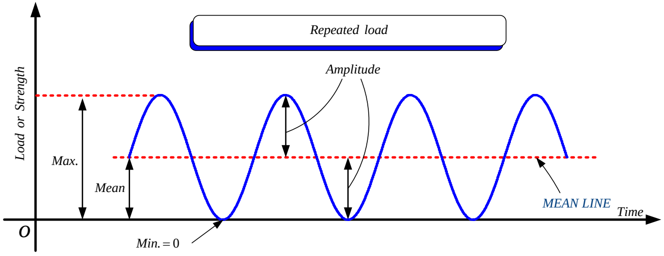


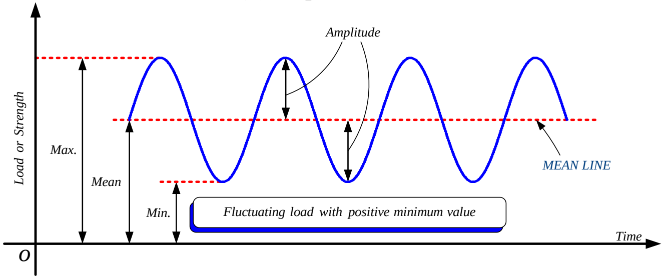
**Fig. 2.** Mechanical load classification: $R$ = Stress ratio as Eq.(1) and $A$ = Amplitude ratio as Eq.(2). [1]



(a) Completely reversed load



(b) Repeated load



(c) Fluctuating load

**Fig. 3.** Variable load. [1]

There are two primary categories of working conditions: 1. The workpiece (or part) rotates under a constant load and 2. The workpiece (or part) is stationary under a variable load, resulting in a dynamic load that fluctuates with a period known as the variable load. As such, this kind of load is split into two sections: 1. The amplitude component will be utilized to compute the alternating stress, also known as the amplitude stress ($\sigma_a$), according to Equation (3), and 2. The mean component will be employed to compute the average stress, also known as the mean stress ($\sigma_m$), as stated Equation (4).

To facilitate the consideration of mechanical design. As a result, three categories have been established for the variable load's characteristics: Fig. 3 illustrates the 1. completely reversed load, 2. repeated load, and 3. fluctuating load. The first instance is usually a laboratory case study. The latter two situations are more common in mechanical designs, though. To be beneficial in the industrial mechanical component design process. These factors lead this research to focus mainly on the latter two cases.

For constant fatigue life (CFL) characteristics, Kim [6] has studied how to predict *S-N* curves at different stress ratios for structural materials in order to identify gaps in the curves' behavior and the impact of stress ratio ($R$) as in Eq. (1). In contrast, this paper examines how to estimate fatigue life from *S-N* curves at amplitude ratios ($A$), as in Eq. (2), that are larger than 1, equal to 1, and less than 1.

$$R = \frac{Stress_{\min}}{Stress_{\max}} \tag{1}$$

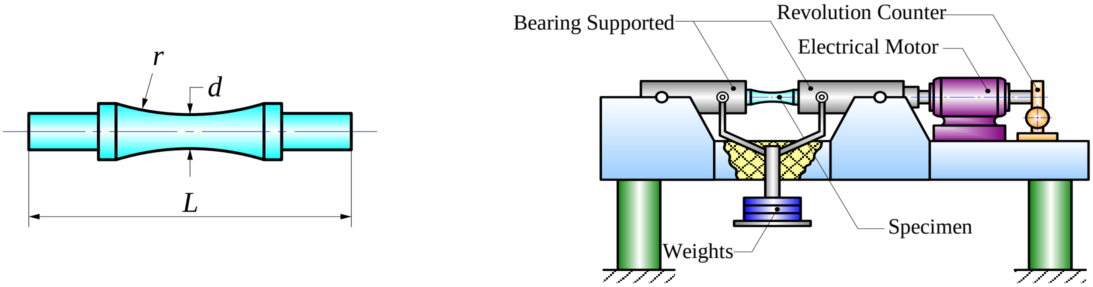
$$A = \frac{Amplitude\ Stress}{Mean\ Stress} \tag{2}$$

$$\sigma_a = \left|\frac{\sigma_{\max} - \sigma_{\min}}{2}\right| \tag{3}$$

$$\sigma_m = \frac{\sigma_{\max} + \sigma_{\min}}{2} \tag{4}$$

## 3. Fatigue Test

A polished surface was found to be the optimal surface for fatigue testing conducted on the specimen depicted in Fig. 4(a) [7]. In order to apply flexural stresses, also known as bending stresses, to the test specimen, it is put on a fatigue testing apparatus [1] with a standard hanging mass. Shrinkage is brought on by compressive bending stresses at the top specimen's surface. Tension bending stresses will cause elongation at the bottom specimen's surface. The top specimen's surface moves toward the bottom and the bottom specimen's surface toward the top every half revolution as the workpiece rotates. Thus, alternating positive and negative flexural stresses of equal amplitude are applied to the test specimen.



(a) Fatigue test specimen or Rotating beam [7]　　(b) Fatigue testing machine [1]

**Fig. 4.** Fatigue test specimen and fatigue testing machine.

As a result, this type of load scenario is known as a completely reversed load. An additional component will be added to the motor that rotates the workpiece: a revolution counter. The counting will stop when the workpiece is torn apart and destroyed. Plot the data as an *S-N* curve after processing them.

## 4. Endurance Limit of Fatigue Test Specimens

Equation (5) can be used to determine the endurance limit of ferrous metal fatigue test specimens ($S'_e$), and equation (6) can be used to determine the ultimate tensile strength at operating temperature ($S^*_{ut}$).

$$S'_e = \begin{cases} 0.5S^*_{ut} & S^*_{ut} \le 1400 \text{ MPa} \\ 700 \text{ MPa} & S^*_{ut} > 1400 \text{ MPa} \end{cases} \quad \textit{For Steels} \qquad \begin{cases} 0.4S^*_{ut} & S^*_{ut} \le 400 \text{ MPa} \\ 160 \text{ MPa} & S^*_{ut} > 400 \text{ MPa} \end{cases} \quad \textit{For Irons} \tag{5}$$

$$S^*_{ut} = k_d S_{ut} \tag{6}$$

In this case, $k_d$, the temperature factor, has a value of 1 at room temperature, and $S_{ut}$ is the test specimen's ultimate tensile strength [2].

### *4.1 Equational Technique*

Applying an equational method to estimate test specimen fatigue life. The fatigue parameters, $f$, $a$, and $b$, as indicated in Fig. 5 and equations (7), (8), respectively, must be used. Equation (9a) is used to calculate the fatigue stress on the test specimen ($\sigma_{rev}$). If this equation is changed, Equation (9b) or Equation (9c) will be generated for the fatigue life of test specimen ($N$). Equation (10) is used to obtain the fatigue strength $S'_{f@10^3}$ at $N$ = 1000 cycles.

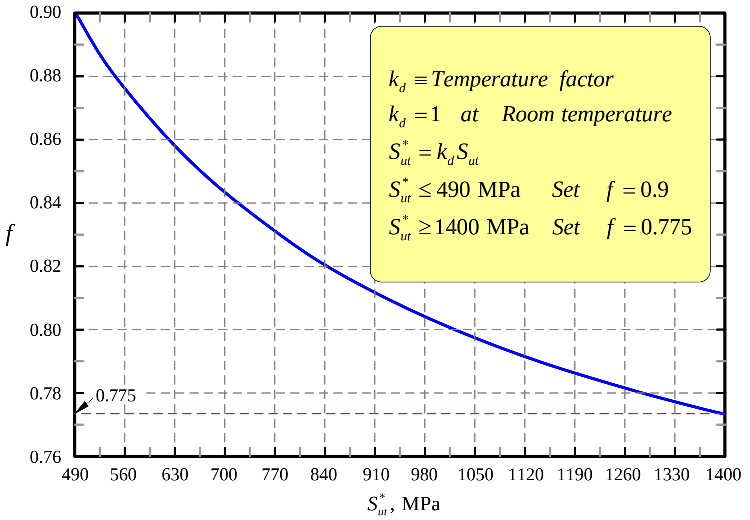


**Fig. 5.** Fatigue parameter *f*. [1, 2]

$$a = \frac{(f \cdot S^*_{ut})^2}{S'_e} \tag{7}$$

$$b = -\frac{1}{3}\log\left(\frac{f \cdot S^*_{ut}}{S'_e}\right) \tag{8}$$

$$\sigma_{rev} = S'_f = a(N)^b \tag{9a}$$

$$N = \left(\frac{S'_f}{a}\right)^{1/b} = \left(\frac{\sigma_{rev}}{a}\right)^{1/b} \tag{9b}$$

$$\log N = \frac{1}{b}\log\left(\frac{S'_f}{a}\right) = \frac{1}{b}\log\left(\frac{\sigma_{rev}}{a}\right) \tag{9c}$$

$$S'_{f@10^3} = a\left(10^3\right)^b \tag{10}$$

Where $\sigma_{rev}$ is the cyclic stress that corresponds to a complete completely reversed stress scenario.

### *4.2 Graphical Technique*

The *S-N* curve generated by the material fatigue test data revealed the nonlinearity relationship (Fig. 6(a)). As a result, the *S-N* curve must be shown on a semi-logarithmic or semi-log scale for convenience of use, as seen in Fig. 6(b), where it is evident that ΔABC and ΔAED are similar. Consequently, equations (11) through (14) can be used to write the relationship. In order to utilize the *S-N* curve for graphical methods, it needs to be flipped as illustrated in Fig. 6(c).

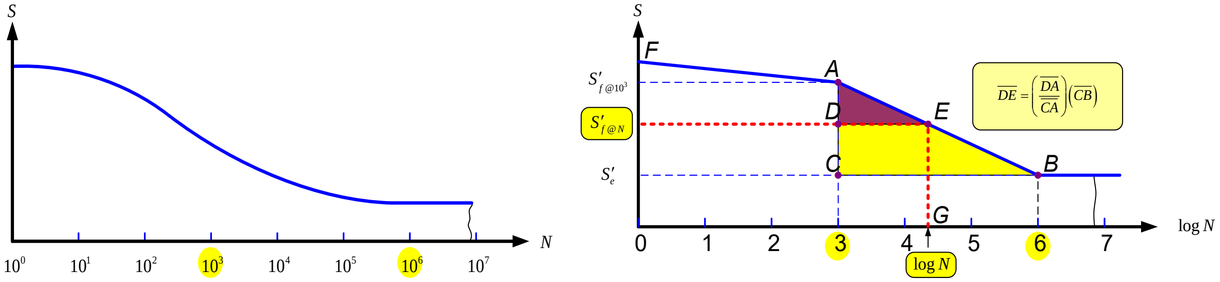
Equation (9c) for the equational technique and the similar triangular properties were used to produce the equation for the fatigue life of test specimens (*N*). Equations (13) and (14), therefore, will represent the new equation for *N*.

$$\overline{DE} = \left(\frac{\overline{DA}}{\overline{CA}}\right)\left(\overline{CB}\right) \tag{11}$$

$$\log N - 3 = \left(\frac{S'_{f@10^3} - S'_{f@N}}{S'_{f@10^3} - S'_e}\right)(6-3) \tag{12}$$

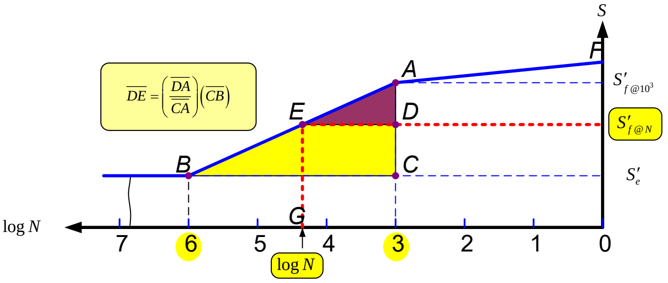
$$\log N = 3 + \left(\frac{S'_{f@10^3} - S'_{f@N}}{S'_{f@10^3} - S'_e}\right)(3) \tag{13}$$

$$N = 10^{\left\{3+\left(\frac{S'_{f@10^3} - S'_{f@N}}{S'_{f@10^3} - S'_e}\right)(3)\right\}} \tag{14}$$



(a) Before the semi-log scale plot [4]

(b) Similar triangles [1]



(c) Flipped *S-N* Curve

**Fig. 6.** *S-N* Curve.

### 4.2.1 Theory for Mechanical Parts Failure Prediction under Dynamic Load

Numerous theories, including Langer, Soderberg, Goodman, Gerber, and ASME-Elliptic, can be used to estimate the fatigue damage of mechanical parts under dynamic stresses [1, 2, 5, 7]. The first cycle of HCF's statics damage is predicted using Langer theory. Fatigue damage is forecast using the remaining theories.

Since the Langer theory (equation (15) and the Goodman theory (equation 16) are well-liked and frequently applied theories, they will be the only ones discussed in this article. They also yield satisfactory, trustworthy prediction results and are linear and user-friendly. Regarding the Goodman theory and Langer theory prediction bounds, they are displayed in Figs. 7 and 8, respectively. Equation (17) serves as the basis for the yield strength in tension at the operating temperature.

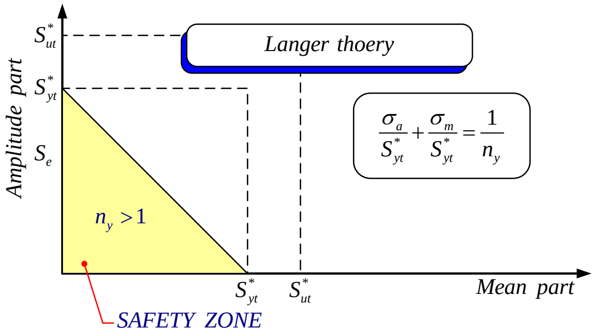


**Fig. 7.** Langer theory. [1]

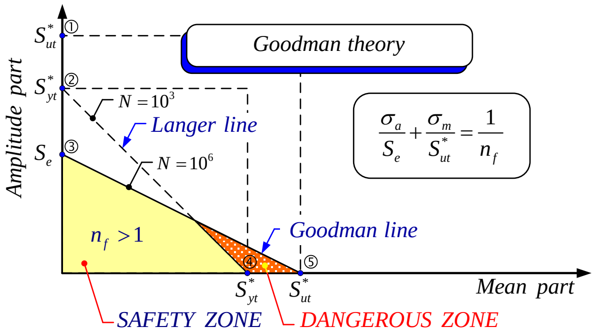


**Fig. 8.** Goodman theory. [1, 8]

$$\frac{1}{n_y}=\frac{\sigma_a}{S^*_{yt}}+\frac{\sigma_m}{S^*_{yt}} \tag{15}$$

$$\frac{1}{n_f}=\frac{\sigma_a}{S_e}+\frac{\sigma_m}{S^*_{ut}} \tag{16}$$

$$S^*_{yt}=k_d S_{yt} \tag{17}$$

Where $n_y$ is the safety factor under statics conditions and $n_f$ is the fatigue safety factor.

### 4.2.2 Steps of Graphical Technique

The following are the steps to estimate test specimen fatigue life graphically.

1. Determine the fatigue parameters, which are *f*, *a*, and *b* from Fig. 5 and equations (7)-(8) respectively.
2. Determine the values of $S'_e$, $S^*_{ut}$, and $S'_{f@10^3}$ using equations (5), (6), and (10) in that order.
3. Calculate $\sigma_a$ and $\sigma_m$.

4. Plot the ①,②,③,④ and ⑤ key coordinates on the Goodman theory on a graph created as illustrated in Fig. 9.
5. Mark the point $P$ at coordinate $(\sigma_m, \sigma_a)$ on Goodman theory.
6. From point ⑤ to point $P$, draw a line, and then extend it to point $Q$, which is coordinate $(0, S'_{f@N})$ or $(0, \sigma_{rev})$, where the line intersects the vertical axis.
7. Use a semi-log scale to plot the *S*-*N* curve. The curve should then be flipped from left to right, as Fig. 6(c) illustrates.

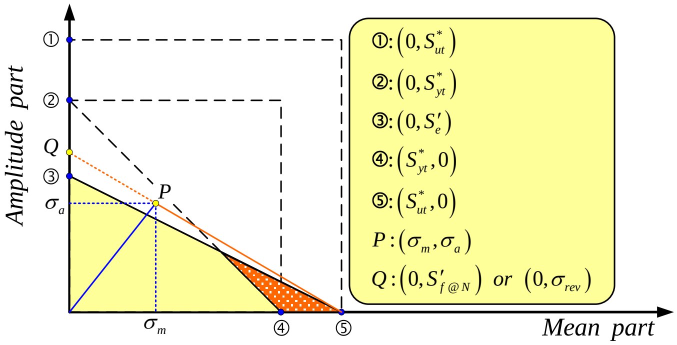


**Fig. 9.** Key coordinates on Goodman theory.

8. Align the *S*-*N* curve and Goodman theory origin points at the same level.
9. Mark points *F*, *A*, and *B*. Then draw a line to connect them as shown in Fig. 6(c).
10. As indicated in Fig. 6(c), project a line from point *Q* parallel to the *S*-*N* curve's horizontal axis so that it intersects the line *AB* at point *E*.
11. As indicated in Fig. 6(c), project a line from point *E* downward perpendicular to the *S*-*N* curve's horizontal axis at point *G*.
12. To determine the approximate life of the fatigue test specimens, read the value of cycle number *N*.
13. To determine the test specimens' fatigue life with greater accuracy, compute *N* using Equation (14).

## 5. Estimation of the Fatigue Life of Test Specimens

### *5.1 Scope of estimation*

This paper estimates the fatigue life of test specimens in the following scope.

1. Materials belonging to the ferrous metals group with $S_{ut}$ values varying between 490 and 1400 MPa were utilized to create the fatigue test specimens.
2. Because the test is conducted at room temperature, $S_{ut} = S^*_{ut}$ since $k_d = 1$.
3. The HCF range is always taken into account for the values of $\sigma_a$ and $\sigma_m$ in every test scenario.
4. All test cases' $\sigma_a$ and $\sigma_m$ values are taken into account if $n_y > 1$ but $n_f < 1$. As a result, it sits inside of Langer theory's safety zone but Goodman theory's finite life design range.
5. The amplitude ratios of $A > 1$ (or fluctuating load with $\sigma_a > \sigma_m$), $A = 1$ (or repeating load $\sigma_a = \sigma_m$), and $A < 1$ (or fluctuating load with $\sigma_a < \sigma_m$) are taken into account in the test.
6. Because this situation frequently arises in mechanical design, all tests take into account a positive mean stress value, or $\sigma_m > 0$.
7. Using AutoCAD software, this article will plot all points and read out the value to ensure accuracy in measuring values.

### *5.2 Input data for estimation*

Table 1 displays the input data used to estimate the fatigue life of test specimens

**Table 1:** The input data used to estimate the fatigue life of test specimens.

| **Case 1** | $S^*_{ut}$ **(MPa)** | $f$ **(-)** | $S'_e$ **(MPa)** | $a$ **(MPa)** | $b$ **(-)** | $S'_{f@10^3}$ **(MPa)** |
|---|---|---|---|---|---|---|
| | 490 | 0.900 | 245 | 793.80 | –0.08509 | 441 |
| **Subcase** | $\sigma_a$ **(MPa)** | $\sigma_m$ **(MPa)** | $A$ **(-)** | $S'_{f@N}$ **(MPa)** | | |
| 1.1 | 214.29 | 140 | 1.53 | 300 | | |
| 1.2 | 200 | 200 | 1.00 | 337.93 | | |
| 1.3 | 159.59 | 260 | 0.61 | 340 | | |

| **Case 2** | $S^*_{ut}$ **(MPa)** | $f$ **(-)** | $S'_e$ **(MPa)** | $a$ **(MPa)** | $b$ **(-)** | $S'_{f@10^3}$ **(MPa)** |
|---|---|---|---|---|---|---|
| | 980 | 0.804 | 490 | 1266.98 | –0.06876 | 788 |
| **Subcase** | $\sigma_a$ **(MPa)** | $\sigma_m$ **(MPa)** | $A$ **(-)** | $S'_{f@N}$ **(MPa)** | | |
| 2.1 | 610.61 | 100 | 6.10 | 680 | | |
| 2.2 | 380 | 380 | 1.00 | 620.67 | | |
| 2.3 | 316.63 | 400 | 0.79 | 535 | | |

| **Case 3** | $S^*_{ut}$ **(MPa)** | $f$ **(-)** | $S'_e$ **(MPa)** | $a$ **(MPa)** | $b$ **(-)** | $S'_{f@10^3}$ **(MPa)** |
|---|---|---|---|---|---|---|
| | 1400 | 0.775 | 700 | 1681.75 | –0.06344 | 1085 |
| **Subcase** | $\sigma_a$ **(MPa)** | $\sigma_m$ **(MPa)** | $A$ **(-)** | $S'_{f@N}$ **(MPa)** | | |
| 3.1 | 857.14 | 200 | 4.29 | 1000 | | |
| 3.2 | 500 | 500 | 1.00 | 777.78 | | |
| 3.3 | 440.18 | 550 | 0.80 | 725 | | |

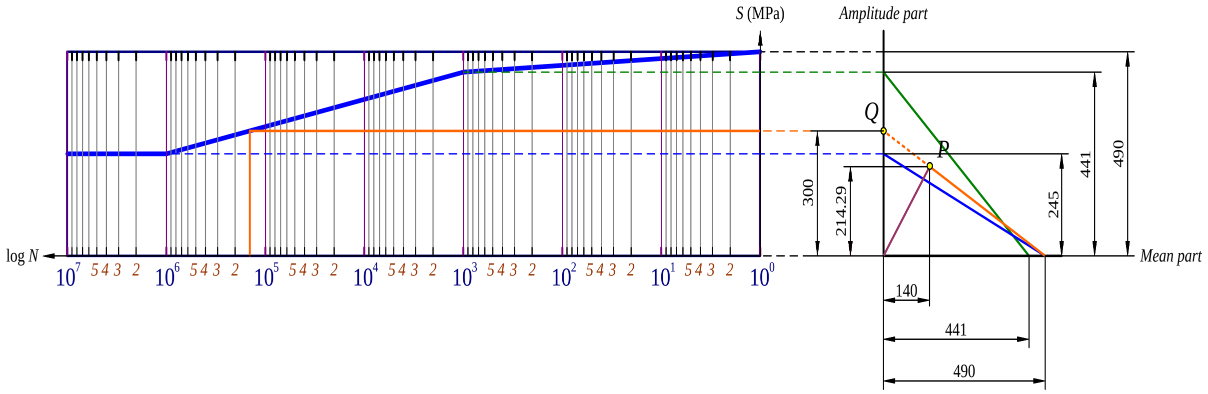
## 6. Result of Estimation of the Fatigue Life of Test Specimens Using Graphical Technique

The life of fatigue test specimens composed of ferrous metals is estimated using graphical approaches. The values in Fig. 9 's vertical axis of the several key coordinates, which are based on Goodman theory, will be taken into consideration to produce the outcomes in Table 2 and the estimation of the life of fatigue test specimens for case 1 to 3 are shown in Fig. 10 to Fig. 12 respectively.

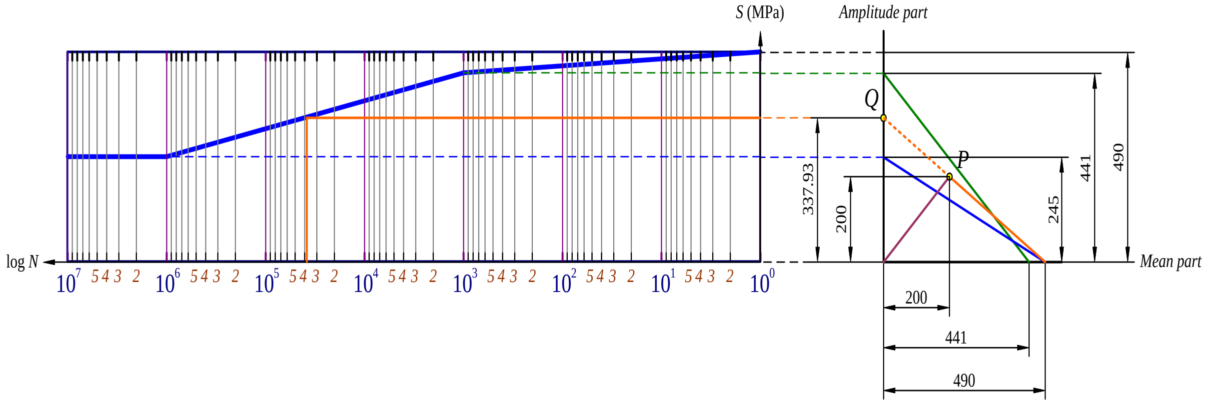
**Table 2:** Results of estimation of the fatigue life of test specimens using a graphical technique.

| **Subcase** | **Ordinate of point** | | | | **Number of cycles** | | ***Err.*** **(%)** |
|---|---|---|---|---|---|---|---|
| | **②** | **③** | $P$ | $Q$ | $N$ **from Eq.(14)** | $N_G$ | |
| 1.1 | 441 | 245 | 214.29 | 300 | $1.44\times10^5$ | $1.4\times10^5$ | 2.78 |
| 1.2 | 441 | 245 | 200 | 337.93 | $3.78\times10^4$ | $3.8\times10^4$ | 0.53 |
| 1.3 | 441 | 245 | 159.59 | 340 | $3.51\times10^4$ | $3.5\times10^4$ | 0.28 |
| 2.1 | 788 | 490 | 610.61 | 680 | $1.22\times10^4$ | $1.2\times10^4$ | 1.64 |
| 2.2 | 788 | 490 | 380 | 620.67 | $4.84\times10^4$ | $4.8\times10^4$ | 0.83 |
| 2.3 | 788 | 490 | 316.63 | 535 | $3.52\times10^5$ | $3.5\times10^5$ | 0.57 |
| 3.1 | 1085 | 700 | 857.14 | 1000 | $4.60\times10^3$ | $4.6\times10^3$ | 0.00 |
| 3.2 | 1085 | 700 | 500 | 777.78 | $2.48\times10^5$ | $2.5\times10^5$ | 0.81 |
| 3.3 | 1085 | 700 | 550 | 725 | $6.39\times10^5$ | $6.4\times10^5$ | 0.16 |

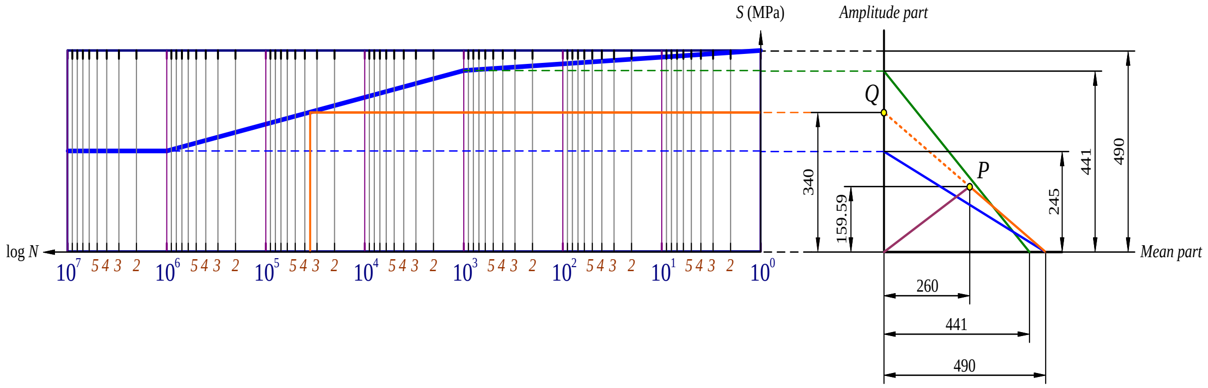
Where $N_G$ is the fatigue life of test specimens using a graphical technique.



(a) Subcase 1.1: $A = 1.53, S'_{f@N} = 300\ \text{MPa}$

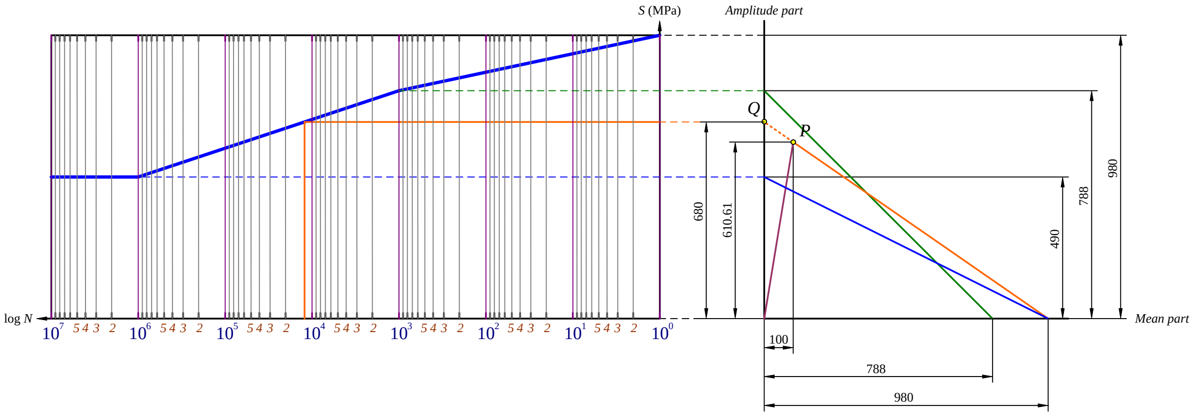


(b) Subcase 1.2: $A = 1.00, S'_{f@N} = 337.93\ \text{MPa}$

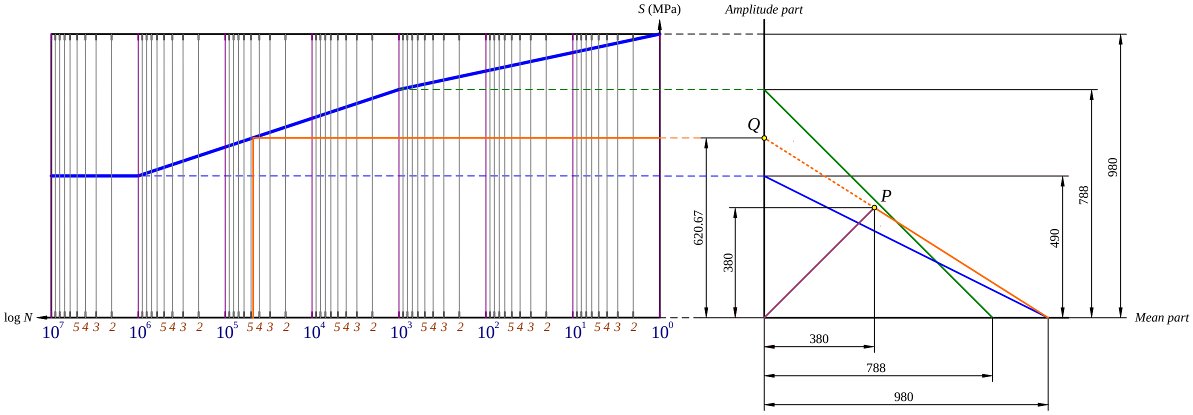


(c) Subcase 1.3: $A = 0.61, S'_{f@N} = 340\ \text{MPa}$

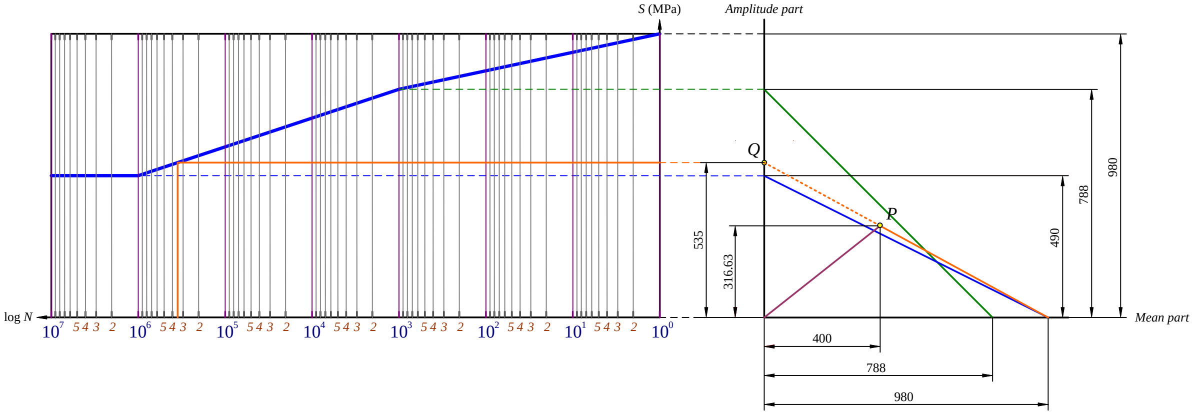
**Fig. 10.** Estimation of the life of fatigue test specimens: Case 1.



(a) Subcase 2.1: $A = 6.10, S'_{f@N} = 680\ \text{MPa}$

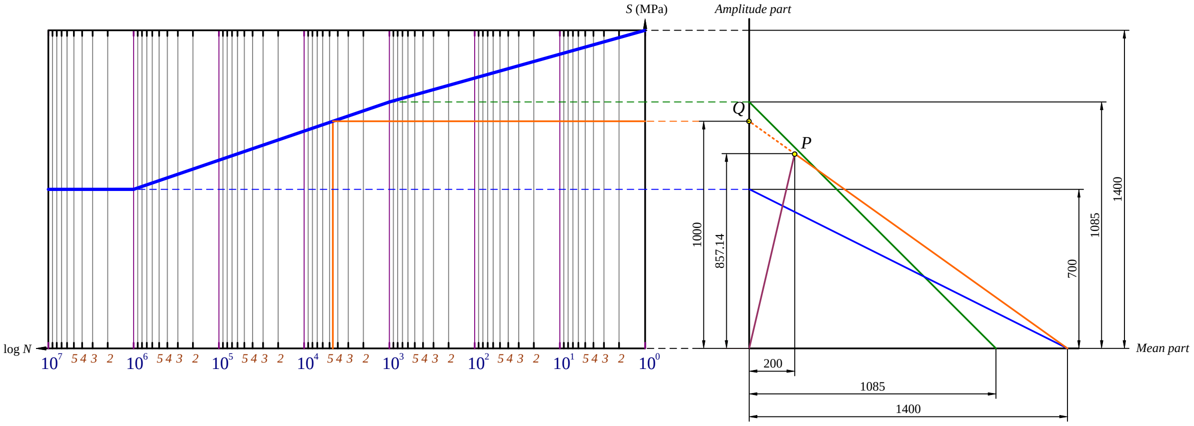


(b) Subcase 2.2: $A = 1.00, S'_{f@N} = 620.67\ \text{MPa}$

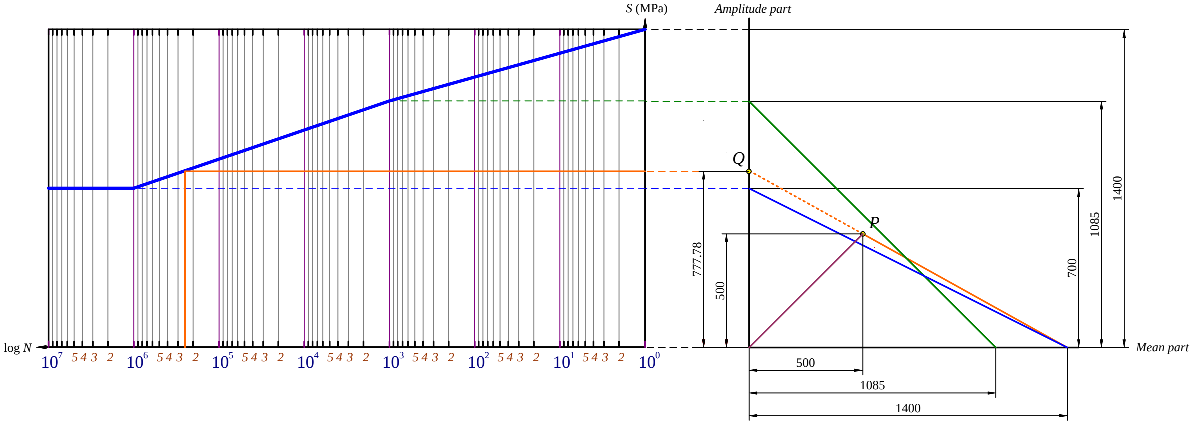


(c) Subcase 2.3: $A = 0.79, S'_{f@N} = 535\ \text{MPa}$

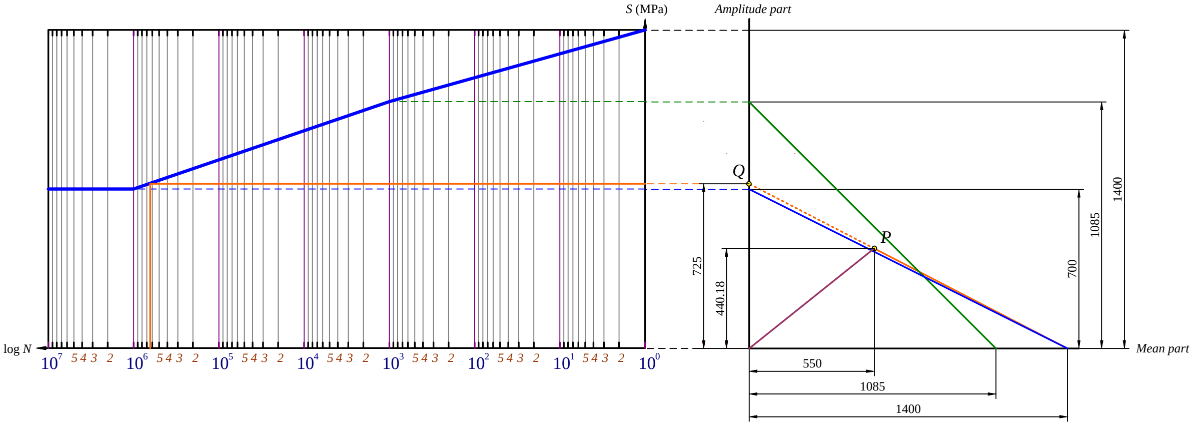
**Fig. 11.** Estimation of the life of fatigue test specimens: Case 2.



(a) Subcase 3.1: $A = 4.29, S'_{f@N} = 1000\ \text{MPa}$



(b) Subcase 3.2: $A = 1.00, S'_{f@N} = 777.78\ \text{MPa}$



(c) Subcase 3.3: $A = 0.80, S'_{f@N} = 725\ \text{MPa}$

**Fig. 12.** Estimation of the life of fatigue test specimens: Case 3.

## 7. Discussion

Because there are a lot of variables, such as the possibility of grain flaws in the material, imperfect surface finish on the workpiece, and variations in the material's strength qualities. As such, it is exceedingly challenging to conduct fatigue testing on materials that have produced a single life value result. This leads to the conclusion that the *S-N* curve for fatigue testing is typically a life band, meaning that the life values may fluctuate somewhat under a single dynamic loading, as Fig. 1(a) illustrates. As a result, the observation for this problem should come first.

This article estimates the fatigue life of test specimens using data from the same experiment, rather than testing the fatigue of materials. The study's findings indicated that the process of drawing the *S-N* curve on a semi-log scale was crucial. The $N_G$ will be significantly erroneously read if there is a discrepancy. Furthermore, the strength values and imported data, including the fatigue parameters $f$, $a$, and $b$, are also significant. This is because all variables are related to each other and ultimately affect the life of the fatigue test specimen.

The need to regularly adjust design parameters when creating industrial mechanical parts under dynamic loads may become apparent to a novice engineer or mechanical designer. To produce a prototype that complies with the design objectives, it may be necessary to make adjustments to the element sizes, material type, design factors, or even the size, placement, or direction of the external load until the intended results are obtained. Changing these variables will immediately affect the designed parts' service life. This is a result of new designers' inadequate understanding of the fatigue mechanisms of the materials. As a result, this causes the aforementioned parameters to be altered incorrectly. Furthermore, efforts should avoid using equational methods to predict the fatigue life of designed parts. It is complicated and wastes a lot of time and money. These result in pricey, subpar designs and delivery delays. It opposes the fundamental QCD paradigm of industrial manufacture as a result. For these reasons, this article offers a solution for novice designers. Using accurate and useful graphics techniques reduces design costs and time.

Mechanical designers can use any basic CAD tool to sketch any shape and measure without having to purchase expensive commercial software. This raises the price of design in vain. Furthermore, the primary objective of this article is to provide low-cost, high-quality mechanical designs. As a result, the fatigue life of the item is assessed using the AutoCAD software as an example. This is a result of the majority of designers' prior familiarity with the program. Alternatively, if you are comfortable using another CAD program, you can also follow the instructions provided in this paper. Although it is valid for the test specimens, the fatigue life estimated under dynamic load using the graphical technique in this article can also be applied in the future to other mechanical parts. Additionally, the graphical technique enhances the mechanical design's flexibility and agility in comparison to conventional methods.

## 8. Conclusion

The present article will take into account fatigue tests conducted at room temperature. For the purpose of covering as much material data as possible, fatigue test specimens were created from ferrous metals with three ultimate tensile strength values of 490, 980, and 1400 MPa, respectively. Amplitude ratio values of $A > 1$ (or fluctuating load with $\sigma_a > \sigma_m$), $A = 1$ (or repeating load $\sigma_a = \sigma_m$), and $A < 1$ (or fluctuating load with $\sigma_a < \sigma_m$) were used throughout the dynamic load test. Considering the often this takes place in mechanical design, the mean stress ($\sigma_m$) will be used as the positive value. In this testing, it was hypothesized that the loading conditions applied to the test specimen would either allow fatigue to develop or be within the safety zone of Langer theory (or $n_y > 1$), or that it is a finite life design in accordance with Goodman theory (or $n_f < 1$). Neither of these hypotheses would result in failure in the first cycle of the HCF. The AutoCAD software then estimates the test specimen's fatigue life using graphical techniques ($N_G$) in order to minimize reading inconsistencies. The life estimate $N$ from equation (14), which was derived from a similar triangle, is compared to the value of $N_G$. Nine subcase studies in all were the outcome of this. An acceptable threshold in engineering is often believed to be a variance of no more than 10%. All scenarios produced highly consistent estimation results, with a maximum percentage error of only 2.78%.

## Nomenclature

| | |
|---|---|
| $A$ | Amplitude ratio, (-) |
| $a$ | Fatigue parameter: coefficient part of cycle, (MPa) |
| $b$ | Fatigue parameter: exponent part of cycle, (-) |

| | |
|---|---|
| $d$ | Minimum diameter of fatigue test specimen, (mm) |
| $f$ | Fatigue parameter: coefficient part of the ultimate tensile strength, (-) |
| $k_d$ | Temperature factor, (-) |
| $L$ | Length of fatigue test specimen, (mm) |
| $N$ | Number of cycles from Equational technique, (Cycle) |
| $N_G$ | Number of cycles from Graphical technique, (Cycle) |
| $n_f$ | Fatigue safety factor, (-) |
| $n_y$ | Yielding safety factor, (-) |
| $R$ | Stress ratio, (-) |
| $r$ | The radius of curvature of the fatigue test specimen, (mm) |
| $S$ | Strength, (MPa) |
| $S_e$ | Endurance limit of machine part, (MPa) |
| $S'_e$ | Endurance limit of fatigue test specimen, (MPa) |
| $S'_f$ | Fatigue strength of fatigue test specimen, (MPa) |
| $S'_{f@10^3}$ | Fatigue strength of fatigue test specimen at $N = 10^3$ cycle, (MPa) |
| $S'_{f@N}$ | Fatigue strength of fatigue test specimen at $N$ cycle, (MPa) |
| $S_{ut}$ | Ultimate tensile strength, (MPa) |
| $S_{ut}^*$ | Ultimate tensile strength at operating temperature, (MPa) |
| $S_{yt}$ | Yield strength in tension, (MPa) |
| $S_{yt}^*$ | Yield strength in tension at operating temperature, (MPa) |
| $\sigma_a$ | Amplitude stress or Alternating stress, (MPa) |
| $\sigma_m$ | Mean stress or Midrange stress, (MPa) |
| $\sigma_{\max}$ | Maximum stress, (MPa) |
| $\sigma_{\min}$ | Minimum stress, (MPa) |
| $\sigma_{rev}$ | The cyclic stress that corresponds to a completely reversed stress scenario. |

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