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Stress Analysis of Welded Joint Portions at Rear-side Footrests of Public Transportation like Human Hauler

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ABSTRACT

Public transportation like Human Hauler (also called as ‘Leguna’) have footrest at the rear side, which is built for purpose of getting into or out of the vehicle. It is not any integral part of the vehicle, so welded with the main frame. However, it is frequently used to carry passengers in our densely populated country. As a result, extra stress is continuously generated on these portions. This research paper highlights how much stress is generated on these welded joint portions. For this evaluation, first of all continuous load data are taken by a strain gauge based load sensor setup in which an Arduino is used as controlling device. All the data was stored in an external SD card. Then using these data, stress at various welded joint portions is calculated. After that, a comparison shows which welded joint portion is the most vulnerable and which is the least.

Keywords: Stress, Welded Joint, Strain Gauge, Public Transportation

1. Introduction

Bangladesh is a densely populated country, which also have scarcity of roads and transport. A number of people used to move from one place to another by local transport. Human Hauler (Leguna) is one of the cheapest mediums of transport for the local people to avail. During the pick-hour period (when schools, office starts or ends), some passengers always taking some risks hanging themselves on the footrest of such vehicle. The footrest is not the integrated part of the vehicle, it has been fabricated (by welding) with the frame to enter and exit from the vehicle. It is noteworthy that, for gathering a number of passengers on the footrest, it is become overstressed. For this reason, there lies a huge threat for failure of that welded joint portion. Moreover, failure of such footrest during running condition might cause great loss. The scope of this study underlying with such case. We want to find out how much stresses are generated on the welded joint portions. Furthermore, we want to assess permissible load that can be applied on a selected type of footrest.

Fig.1 An under aged helper of the driver of tiny human-hauler, called 'Leguna', gets on the vehicle's roof with another person as the footrest, where the helpers usually stand, is occupied by seven passengers hanging from window railings. (Photo: Asif Mahmud Ove, October 02, 2016, Source: bdnews24.com).

The objectives of this study are

i. To design and fabricate strain gauge load cell based load-measuring device, which can take continuous data.
ii. To collect load data by putting load measuring device setup at the footrest of a suitable Human Hauler.
iii. To analyze stresses at various welded joint portions at the footrest of that Human Hauler and calculate stress value by data achieved from load measuring device.
iv. To evaluate which welded joint portion is the most stress-prone and add necessary recommendations.

This paper is organized as follows:
In the first section, background of the study is described briefly as well as objectives. In the second section all the necessary equations with nomenclature is shown. Previous studies on stress analysis is also briefed here. Experimental setup with proper description and figures is shown in the third section. Flow chart of the study is also given here. Section four depicts the generated stress at various portion of the selected footrest. Here a comparison of generated stress at various portions is also shown assuming hundred kg applied load. In the fifth section, the authors add some recommendation about the selected footrest. Finally, in the conclusion part a brief discussion on overall study is shown.

2. Literature Review

We had to examine two kind of stresses, as our studyis a circumstance of combined loading,

i. Primary shear stresses for external forces
ii. Secondary shear stresses for bending and torsional moment.

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i. Stresses in Welded Joint in Torsion [1]:

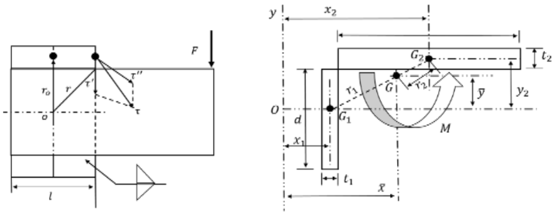


Fig.2 This is a moment connection; such a connection produces torsion in the welds. The shear stresses shown are resultant stresses [1]

A cantilever of length *l* welded to a column by two fillet welds illustrates in figure 2. A shear force *V* and a moment *M*is produced as the reaction at the support of a cantilever.A primary shear is produced by the shear force in the welds of magnitude

$$\tau' = \frac{V}{A} \quad (1)$$

Secondary shear or torsion is generated by the moment at the support and this stress is given by the equation

$$\tau'' = \frac{Mr}{J} \quad (2)$$

where *r* is the distance from the point in the weld of interest to the centroid of the weld group and the second polar moment of area of the weld group about the centroid of the group is *J*. These equations can be solved and the results combined to obtain the maximum shear stress when the sizes of the welds are known.

Fig.2 depicts two welds in a group. Throat areas of the welds is represented by the rectangles. Weld 1 has a throat thickness *t1 = 0.707h1*, and weld 2 has a throat thickness *t2 = 0.707h2*. It is noted that *h1* and *h2* are the respective weld sizes. So The area of throat of both welds together is

$$A = A_1 + A_2 = t_1 d + t_2 b \quad (3)$$

This area *A*is to be used in Eq. (1)

The X-axis in Fig.2 passes through the centroid *G1* of weld 1. The second moment of area about this axis is

$$I_x = \frac{t_1 d^3}{12} \quad (4)$$

Similarly, the second moment of area about an axis through *G1* parallel to the Y-axis is

$$I_y = \frac{d {t_1}^3}{12} \quad (5)$$

Thus the second polar moment of area of weld 1 about its own centroid is

$$J_{G1} = I_x + I_y = \frac{t_1 d^3}{12} + \frac{d {t_1}^3}{12} \quad (6)$$

In a similar manner, the second polar moment of area of weld 2 about its centroid is

$$J_{G2} = \frac{t_2 b^3}{12} + \frac{b {t_2}^3}{12} \quad (7)$$

The centroid *G* of the weld group is located at

$$\bar{x} = \frac{A_1 x_1 + A_2 x_2}{A} \bar{y} = \frac{A_1 y_1 + A_2 y_2}{A} \quad (8)$$

Now, using the parallel-axis theorem, we find the second polar moment of area of the weld group to be

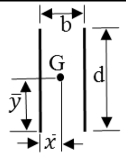
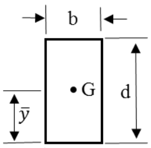
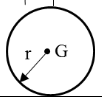
$$J = (J_{G1} + A_1 {r_1}^2) + (J_{G2} + A_2 {r_2}^2) (9)$$

This is the quantity that should be used in Eq. (2). The distance r must be measured from G and the moment *M*computed about *G*. Since the throat width of a fillet weld is *0.707h*, the relationship between *J* and the unit value is

$$J = 0.707 h J_u \quad (10)$$

in which J_u is found by conventional methods for an area having unit width. The transfer formula for J_u must be employed when the welds occur in groups, as in Fig. 2. Table 1 lists the throat areas and the unit second polar moments of area for the fillet welds encountered in our selected footrest

Table 1 Torsional Properties of Fillet Welds [1]

Case	Weld	Throat Area	Location of G	I_u
2		$A = 1.414hd$	$\bar{x} = \frac{b}{2}$ $\bar{y} = \frac{d}{2}$	$J_u = \frac{d(3b^2 + d^2)}{6}$
5		$A = 1.414h(b + d)$	$\bar{x} = \frac{b}{2}$ $\bar{y} = \frac{d}{2}$	$J_u = \frac{(b + d)^3}{6}$
6		$A = 1.414\pi hr$		$J_u = 2\pi r^3$

ii. Stresses in Welded Joint in Bending [1]:

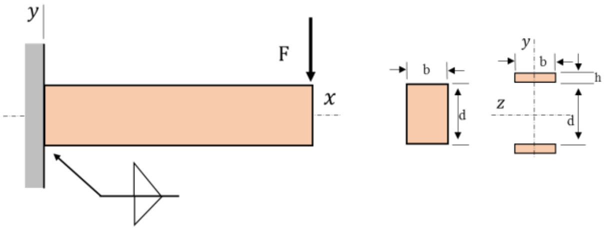


Fig.3A rectangular cross-section cantilever welded to a support at the top and bottom edges [1]

A cantilever welded to a support by fillet welds at top and bottom is shown in figure 3. A shear-force reaction *V* and a moment reaction *M*is shown by a free body diagram of the beam. A primary shear is produced by the shear force in the welds of magnitude where A is total area of throat.

$$\tau' = \frac{V}{A} \quad (11)$$

The moment M induces a horizontal shear stress component in the welds. Treating the two welds of Fig. 3 as lines we find the unit second moment of area to be

$$I_u = \frac{bd^2}{2} \quad (12)$$

Based on weld throat area, the second moment of area *I*is

$$I = 0.707 h I_u \quad (13)$$

The nominal shear stress at throat is to be

$$\tau'' = \frac{Mc}{I} \qquad (14)$$

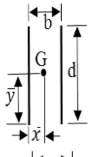
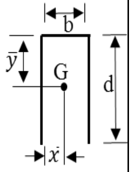
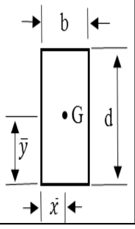
The distance d between the two welds determines the second moment of area in Eq. (14).

The secondary shear of Eq. (14) and primary shear of Eq. (11) are then combined as vectors to give

$$\tau = (\tau'^2 + \tau''^2)^{1/2} \qquad (15)$$

Table 2lists the throat areas and the unit second polar moments of area for the fillet welds encountered in our selected footrest.

Table 2 Bending Properties of Fillet Welds [1]

Case	Weld	Throat Area	Location of *G*	I_u
2		$A = 1.414hd$	$\bar{x} = \frac{b}{2}$ $\bar{y} = \frac{d}{2}$	$I_u = \frac{d^3}{6}$
5		$A = 0.707h(b + 2d)$	$\bar{x} = \frac{b}{2}$ $\bar{y} = \frac{d^2}{b + 2d}$	$I_u = \frac{2d^3}{3} - 2d^2\bar{y} + (b + 2d)\bar{y}^2$
6		$A = 1.414h(b + d)$	$\bar{x} = \frac{b}{2}$ $\bar{y} = \frac{d}{2}$	$I_u = \frac{d^2}{6}(3b + d)$

2.2 Previous Studies:

As we selected a topic, which has never studied before, here some study about stress analysis has been briefly discussed. Many steel structures such as road and railway bridges, oil and gas exploitation platforms (offshore platforms), windmills, and so on are subjected to a high number of repetitive cyclic stresses during their lifetime. Over time, those stresses can cause damage, such as cracks, at critical locations. This phenomenon is called "fatigue." It can be defined as a progressive localized process in which damage continuously accumulates in a structure or structural element due to the effect of cyclic loading, which has much less intensity than the static resistance of an observed structure or structural detail.

A study by Oehme [2] shows how fatigue takes third place as the cause of failure of fatigue prone steel structures. Fatigue cracks are usually initiated at locations of a sudden change in the geometry or notch locations[3], where there is a localized increase of stress (stress concentration). The smaller the notch is, the bigger the stress concentration is, and in the end, fatigue life is shorter. The most common locations in steel structures prone to fatigue where fractures are made are welded joints as these are locations of high stress concentrations. Obviously, fatigue assessment becomes inevitable during design and maintenance because welding is a primary process of connecting elements in structures that are previously mentioned. Furthermore, in the last few years, high-strength steels are being used more frequently for steel structures due to the decrease in self-weight of the structure, and although its use has a positive effect, fatigue becomes a leading ultimate limit state.

The term "fatigue" was first mentioned in the 19th century to describe the failure of a structure or structural element subjected to cyclic loading. Research of fatigue was first carried out by August Wöhler who investigated the failure of train axles. He detected that structural loading that is well below its static resistance does not cause any damage. However, in the case of repeating the same loading over a prolonged period, it can cause failure of the structure or structural element. In the 19th century, fatigue was a mysterious phenomenon because fatigue damage could not be seen, and failure occurred without any warning. In the 20th century, it became known that cyclic (repeated) structural loading initiates the fatigue mechanism and, respectively, crack initiation and propagation. Since this fatigue phenomenon became recognized, much research has been conducted, and significant progress in developing fatigue assessment methods, understanding the mechanism of fatigue of structures and materials, and the designing of fatigue resistant details has been made. However, this phenomenon still requires further investigation [4].

Schütz [5] as well as Mann [6] give a chronology of fatigue development from 1837 to 1994 in his collection of ¨ 21,075 literature sources in his four books that are concerned with the fatigue problem of materials and structures from 1838 to 1990. Cui [7] made a review of fatigue assessment methods from 2002 and the factors that affect fatigue behavior of structures and materials. An understanding of the fatigue mechanism is a prerequisite when considering different factors that affect fatigue life and choosing appropriate assessment methods. The fatigue life of a structure or structural element is measured from the crack initiation and crack propagation phase. Cracks made by cyclic loading usually occur at the surface of a structural element where fatigue damage comes in the form of microscopic cracks in crystallographic slip planes. This phase is called the "Crack Initiation Phase." Furthermore, cracks propagate from localized plastic strain to macroscopic size in a direction perpendicular to the loading direction, which presents the crack propagation phase [8]. The crack initiation phase also includes crack growth on a microscopic scale, but it still cannot be seen by the naked eye. It is very hard to determine the point between the phases of crack initiation and propagation. In the crack initiation phase, fatigue is a surface phenomenon and depends on material surface characteristics and environmental conditions, while crack propagation depends on the characteristics of the material the crack is spreading through. Forsyth [9]first recognized these two phases, which is one of the biggest accomplishments in research of fatigue of metals in the 20th century. The mechanism of fatigue in different materials and structures is widely described by Schijve [8] in his book. Modern fatigue theories separately analyzed every phase of the fatigue process. Crack initiation theories are based on the assumption that fatigue cracks appear with local stress or strain concentrations on the surface of a structural element because of different geometrical shapes like holes, notches, discontinuity, and so on. Crack propagation and final fracture (failure) is analyzed by fracture mechanics that considers the crack propagation rate in relation to the stress state in crack tip.

3. Research Framework

First of all, weconstructed a portable device by which data collection procedure will be easy and efficient. To find necessary data effectively, weused following equipment-

a) Load cell (4) – sturdy steel construction with strain gauge(0-50 kg)
b) Arduino UNO
c) Differential Amplifier (HX711)
d) SD card module
e) LED Light
f) Frame

We took some assumptions to conduct the research. These are described briefly below:

i) Pick-Hour Period:According to school & office time, We assumed three pick hour periods which are-

a) 7:00 am - 9:00 am
b) 11:30 am - 1:00 pm
c) 4:30 pm – 8:30 pm

All the data was taken at these periods.

ii) Route:We took two routes for research data. These are

a) Bahaddarhat – Amtol.
b) Pared Corner – Barek Building.

iii) Residual Stress: Since heat is used in the welding operation, there are metallurgical changes in the parent metal in the vicinity of the weld. In addition, residual stresses may be introduced because of clamping or holding or, sometimes, because of the order of welding. Usually these residual stresses are not severe enough to cause concern; in some cases a light heat treatment after welding has been found helpful in relieving them. When the parts to be welded are thick, a preheating will also be of benefit. If the reliability of the component is to be quite high, a testing program should be established to learn what changes or additions to the operations are necessary to ensure the best quality [1]. As necessary data are not available for residual data, We took residual stress asnegligible.

3.3 Load Measuring Device Setup:

Firstly, we made load measuring device frame. We put load cells on four corners. Arduino, Differential amplifier (HX711), SD Card Module are placed according to the circuit diagram inside the frame.

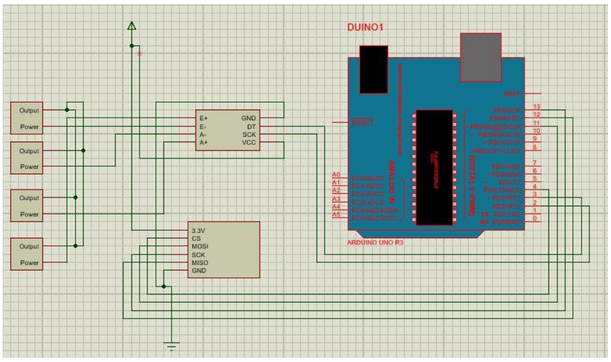


Fig.4 Circuit Diagram

Then We made necessary connections. We also attach a cover to protect my device and to collect data easily. Cover is made by Nylon sheet and top of it a GI sheet is placed which is bent at both edges. A magnet is attached to the frame which clings to GI sheet. We also attached an LED to ensure data collection.

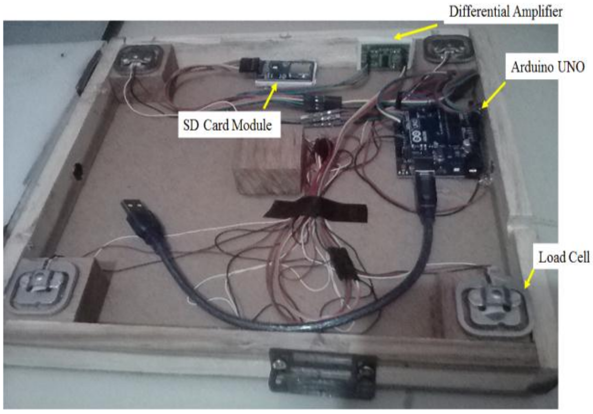


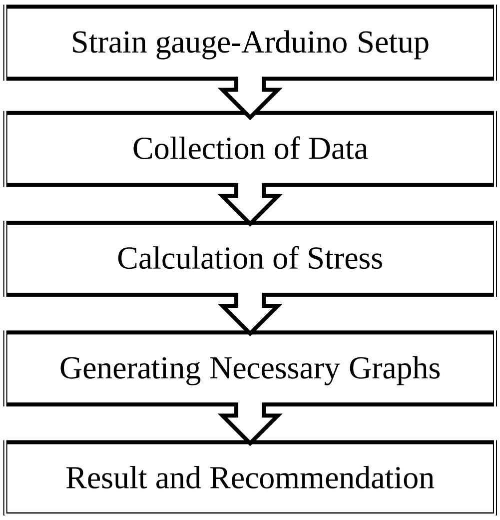
Fig. 5 Load measuring device set up (Inside view)

After making the device, We calibrated it with known weight. Note that the device gives two data every second as programmed.Then We put the device over the footrest of a Human Hauler (Leguna). My experiment date was Friday (5 October 2018). My experiment route was Bahaddarhat to Amtol and time was at about 5:45pm. Necessary measurement was taken by compass and scale.

We found about 1500 data within 25 minutes, which was stored on the SD card. After that these data has been analyzed. Actually more than 3000 data was expected but We think the connection between power bank and Arduino was a little bit loose. That’s why it misses almost half portions of data. However the amount of data collected is fairly enough to analyze stresses and also to conduct this study.

Fig.6 Experiment Moment

3.4 Flow Chart of the Research



4. Data Analysis and Result

There are too many types of footrests available. Of them, We only took one for analysis. All the necessary geometrical measurements were taken at first, which is given in Fig.7

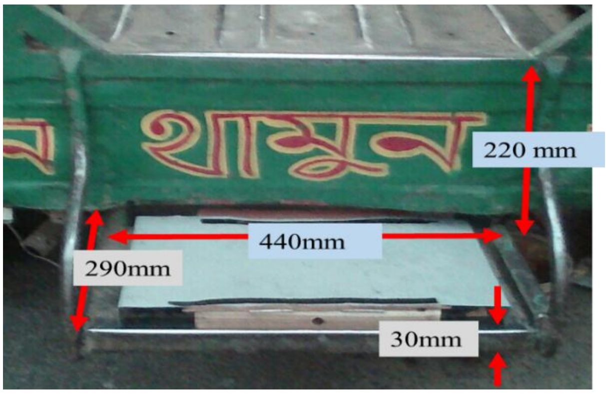


Fig.7 Necessary geometrical measurements of selected footrests

4.2 Analysis

We analyzed six welded joint portions and evaluated the highest stress-prone portions. Here primary shear and secondary shear (i.e. bending) exists considering the structure. Therefore, We calculated the stresses using Table 2 and according to the equations described in 2.1

Fig.8 Analysis of footrest structure welded joint (All the cases are previously mentioned at Table 1.2)

4.3 Results

The Highest stress-prone portions of the footrest We analyzed is for case 2

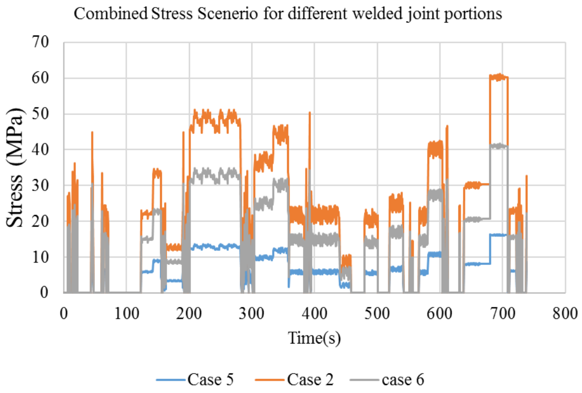


Fig.9 Combined Stress Scenario for different welded joint portions

If a load of 100 kg is assumed, then generated stresses should like following

Table 3 Comparison of Stresses at various points

Case No	Combined Stresses(MPa)
5	10.01
2	37.31
6	25.42

5. Recommendation

i. Though information about electrode is unknown, we can consider known value to evaluate the maximum permissible load that can be applied on the footrest at a time.

Table 4 Minimum Weld-Metal Properties [1]

AWS Electrode Number	Tensile Strength kpsi (MPa)	Yield Strength, kpsi (MPa)	Percent Elongation
E60xx	62 (427)	50 (345)	17–25
E70xx	70 (482)	57 (393)	22
E80xx	80 (551)	67 (462)	19
E90xx	90 (620)	77 (531)	14–17
E100xx	100 (689)	87 (600)	13–16
E120xx	120 (827)	107 (737)	14

Table 5 Stresses Permitted by the AISC Code for Weld Metal [1]

Type of Loading	Type of Weld	Permissible Stress	Factor of Safety (n)
Tension	Butt	0.60S_y	1.67
Bearing	Butt	0.90S_y	1.11
Bending	Butt	0.60–0.66S_y	1.52–1.67
Simple compression	Butt	0.60S_y	1.67
Shear	Butt or fillet	0.30S_{ut}	

If we use E60xx electrode,
Permissible stress for shear will be =.3 × 427 MPa=128.1 MPa
Permissible stress for bending will be =.6 × 345 MPa=207 MPa
Now if 555 kg load is put on the footrest then the generated stress will be 207 MPa.
That meansmore than 6 persons should not stand together considering other factor.

ii. For the welded joint similar with Case 2, if the dimension *d* changes, generated secondary shear stress i.e. bending stress will also changes. So maximum load carrying capacity decreases.

Table 6 Effect of *d* on case 2

d (mm)	Permissible Bending Stress (MPa)	Load Allowed (Kg)
30	207	555
25	207	322
20	207	165
15	207	70

According to the results of the study, some recommendations are given below:

i. Every vehicle which have footrest should undergo with Non Destructive Testing after few years it started operation to check whether if there exists any crack or not. If found any, it should be removed by proper operations.
ii. Welding should be done with electrode E120XX series to get high strength.
iii. The dimension 'd' should be more than 30 mm for case 2

6. Conclusion and Further Study

As welding is a very important tool for joining similar and dissimilar metals, stress analysis of welded joint is always play an important role to design any component having welding joint. Moreover, as stress is variable, so the welded joint portion may fail due to very smaller amount of load then predicted. Therefore, fatigue stress analysis should be done at various welded joint portion. Another crucial part of the research is that it implies on public transportation which is a very much neglected sector in our country. Transportation like human hauler have welded footrest which is built for purpose of getting into or out of the vehicle. Unfortunately, it is also used to carry passengers in our densely populated country. As a result, extra stress is continuously generated on those portions. Therefore, this research depicted the actual scenario on this topic whether it is safe or unsafe.It should also be noteworthy that accidents can occur due to various reasons. But this paper only gives the attention on welded joint safety factor of footrests at Human Hauler. There are other models of footrest. Study should be done on those in future.Then hopefully a guideline can be set on this sector.

REFERENCES

[1] Budinas & Shigley (9th edition) " Mechanical Engineering Design" McGraw Hill publishers, page (475-497)
[2] P. Oehme, (November 1989) "Damage analysis of steel structures," in *Proceedings of the International Association for Bridge andStructural Engineering (IABSE)*, P-139/89, Z¨urich, Switzerland.
[3] R. Haghani, M. Al-Emrani, and M. Heshmati,(2012) "Fatigueprone details in steel bridges," *Buildings*, vol. 2, no. 4, pp. 456–476.
[4] J. Schijve, (2004) *Fatigue of Structures and Materials*, Kluwer Academic Publishers, Dordrecht, Netherlands.
[5] W. Schütz, (1996)"A history of fatigue," *Engineering FractureMechanics*, vol. 54, no. 2, pp. 263–300.
[6] J. Y. Mann, (1990)"Bibliography on the fatigue of materials," in *Components and Structures*, vol. 1–4, Pergamon Press, Oxford, UK.
[7] W. Cui, (2002) "A state-of-the-art review on fatigue life prediction methods for metal structures," *Journal of Marine Science and Technology*, vol. 7, no. 1, pp. 43–56, 2002.
[8] J. Schijve, *Fatigue of Structures and Materials*, Kluwer Academic Publishers, Dordrecht, Netherlands, 2004.
[9] P. J. E. Forsyth,(1969) *The Physical Basis of Metal Fatigue*, American Elsevier Pub. Co., New York, NY, USA.