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Experimental Analysis of a Bus Structure Section

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***Abstract* - The objective of this research work is to reproduce in a test specimen, the fatigue failure that occurs in a damaged section of a structure. There is a structural problem, that is, the presence of a fracture at a certain point in the structure of the bus, starting at this point and growing progressively, causing damage. The steps of a methodology were applied to physically reproduce the fatigue failure in a representative specimen of a section of the bus structure, where the failure is located and up to the instrumentation of the testing machine and performance of the fatigue test. Subsequently, the results are analyzed and conclusions are made based on the results obtained in the laboratory test.**

Keywords: Failure, Fatigue, Stress, Specimen test.

I. INTRODUCTION

The objective of fatigue testing is to obtain information regarding the fatigue behavior of a particular material and/or geometry [1]. Fatigue testing is necessary to obtain basic information about material properties, in the same way that information about the yield strength and modulus of elasticity of a material is obtained from a tensile testing. As far as possible, the material conditions, stress ranges and type of loading should be similar to actual service conditions in order for the results to be useful for design. Various types of fatigue loads, specimens, environments, and test equipment are used [2].

Fatigue testings generally require significant experimental time and dedication, implying that these testing are costly relative to simple testings to determine other mechanical characteristics. It requires large investments in experimental fatigue programs, careful planning of the test program, experimental procedures, and evaluation of the results.

Planning should always start with an explicit definition of the problem to be investigated. In general, two types of fatigue tests are considered [3]:

I. Small scale laboratory tests to obtain fundamental information on material behavior. For example ASTM E 647 Standard recommends the specimens for determining the threshold value and crack growth curve in laboratory, Fig. 1.

Figure 1: Crack growth testing

II. Testing of real elements that are components of machines or structures. Testings are performed on prototypes of real components or a computational simulation of the component is performed. It is rarely possible to use actual service loads, so engineers require a reduced specification that is still representative of the operating environment.

Generally, these testings with real (or simulated) components are carried out to obtain information on their total life. To perform these fatigue testings, structures and devices are built [4]. Since real elements are tested, the information obtained can be used directly in the design. Fig. 2 shows a simulation testing of a complete vehicle chassis with 12 hydraulic actuators supplying vertical, lateral and longitudinal loads at the four corners of the test vehicle.

Figure 2: Vehicle testing

Great's structures, such as an automobile, bus or airplane structure, require specialized test equipment. The structure is then usually loaded by a number of hydraulic actuators with electrohydraulic systems controlled by a computer.

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In the automotive industry, certain types of testings are performed on complete automobiles [5]. A test on real sizes with correct service load selection should reveal any weaknesses of the structure, in order to modify it before mass production starts. In fact, such a testing is done mostly, to consider whether all parts of the structure are working properly, without deterioration of any part of the structure after the testing time.

In the aviation industry, testings are also performed to prove aircraft safety and to comply with navigation regulations.

Fatigue testings are performed on real structural components under conditions that simulate real loads and environment. These testings will have to be carried out on full scale models, in order to reproduce in a more adequate way the real operating conditions of the structure and thus to know its behavior up to failure limit situations. However, these testings are difficult to perform, time consuming, and generally very costly.

Therefore, simple specimens simulating structural components are tested. Generally, these specimens are tested to failure to obtain information on the total fatigue life of the components.

In this work, the problem of reproducing a mechanical failure related to a structure is the central part and the objective is to show the use of a methodology. Figure 3 show the drawing of the bus structure.

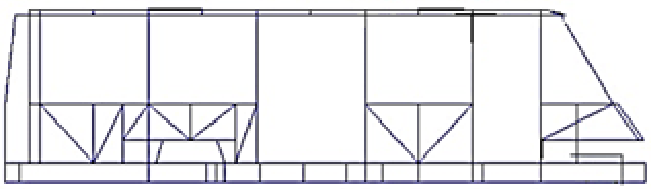

Figure 3: Drawing of the bus structure

II. METHODOLOGY

Premature failures occur in an urban bus, specifically in its structure, during the public transportation service it provides. The causes of the failures are unknown, as well as the position of the critical stress points where they start.

The reason for this research is synthesized as follows:

"In a bus structure a failure has been observed due to a set of solicitations, Fig. 4. From such observation and making a finite element analysis, the starting point of the failure was detected and located. What motivates this research is to reproduce such failure by performing testings in a laboratory."

Figure 4: Failure of the bus structure

Using computational analysis in recent research, the most loaded structural details in bus structures have been identified [6], which show coincidence with the failure prone critical points studied in this research.

The selection of the load to perform the finite element analysis was determined according to the results obtained in a series of testings of the vehicle previously performed. Figure 5 shows the finite element simulation of the specimen, which shows the point of highest stress coinciding with the origin of the crack obtained in the fatigue test, specifically on the lower side of the short structural crosshead of the specimen.

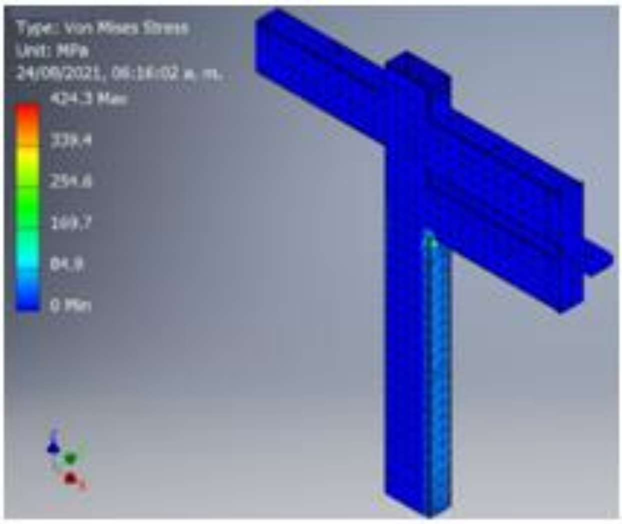

Figure 5: Finite element simulation of the tested specimen

2.1 Problem definition and constrains

The problem is a question arising from a topic or research. One of the greatest difficulties for the researcher is to plan and delimit the study problem [7].

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Consider the following problem:

"It is required to reproduce in the laboratory a failure that happens in a bus structure".

It is important to know the mechanical behavior of the bus structure with the state of loads that are causing the failure. The fundamental restrictions are the following:

- The analysis area is fixed and known.
- The estimated testing time is 24 hours.
- The load that the testing machine can apply is uniaxial.
- Torsional loading is considered.
- The analysis is dynamic.
- The failure and its characteristics are fixed and known.
- The test performed is by fatigue, in an Instron servo-hydraulic machine.

With the problem formulated above and its constraints find:

- The loads that reproduce the particular stress state in a chosen zone of the structure.
- Use the parameters (loads) to design a specimen.
- Obtain a dynamic parameter to test the specimen under controlled conditions.
- Reproduce the failure.

2.2 Hypotheses and basic assumptions

Consider the following hypothesis: "Failure at a critical point in a bus structure can be reproduced in laboratory under controlled loading conditions. The determination of the causes and the reproduction of the failure depend on:

1. Saint Venant's principle.
2. The application load of the test is the resultant of the loads to which the structure is subjected.
3. The acting force in the dynamic problem depends on the estimated time of the test and the number of application cycles.
4. The failure problem satisfies Newton's Laws.
5. A torsional load at a critical point is proposed as a possible cause of failure".

The basic premises are as follows:

1. Saint Venant's Principle. A system of loads applied to a medium can be replaced by another statically equivalent system. The state of stresses and strains of the medium does not vary at a considerable distance from the points of application of the equivalent system of loads.
2. The testing application load is the resultant of the loads to which the structure is subjected. If, due to the operating characteristics of the testing machine, the load application must be uniaxial, then all equivalent system loads related to the structure must be reduced to the resultant of such loads. The resultant is equal to the uniaxial load required in the testing machine.
3. The acting force in the dynamic problem depends on the estimated testing time and the number of application cycles. If the failure reproduction must occur within 24 hours, then the dynamic force to be applied is a function of the operating parameters of the testings machine, the estimated testing time and the number of application cycles in the fatigue testing.
4. The failure problem satisfies Newton's Laws.
   4.1) Law of inertia.
   4.2) Laws of balance.
   4.3) Principle of action and reaction.
5. The cause of the failure problem is for torsion. Some generalizations can be made. Solid sections having the same cross sectional area are stiffer. On the other hand, an element composed of long slender sections that are not closed like a tube is very weak and torsionally flexible. Examples of flexible cross-sectional shapes are common structural shapes such as U-shaped, L-shaped and I-shaped. Tubes, solid bars and structural rectangular tubes are very rigid.

2.3 Research methods

The fatigue testing was performed on a section of the structure, from the original material; a frame was built, so that when using the testing machine, the load can be transmitted very similar to reality.

This section proposes the steps of the methodology used to reproduce the failure in the laboratory.

A1. Steps for the construction of the specimen and the loading system:

A1.1. Design a real specimen (a portion of the structural section) made of the bus material where the region of analysis is located, region where the failure will be reproduced.

A1.2. Design the loading system (frame) to perform the fatigue testing.

A1.3. Mount the specimen in the testings machine and incorporate the loading system.

Fig. 6 shows the specimen design that physically represents the upper right section of the front door frame.

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Figure 6: Design of the bus structure specimen

A2. Steps for the instrumentation of the specimen and the loading system:

A2.1. Instrument with electrical strain gauges at the point of failure initiation.

A2.2. Instrument a load cell and adapt it to the element or device with which the work load will be applied.

A3. Steps for the preparation of the testing in the laboratory:

A3.1. Apply penetrant liquids on the test specimen and to detect possible cracks before applying the load.

A3.2. Connect the extensometer located at the point of failure initiation and the load cell to an oscilloscope. Strains were monitored using strain gauges during the testing.

A4. Action steps of the testing in the laboratory:

A4.1. Apply the static load obtained to measure the maximum stresses at the failure initiation point.

A4.2. Apply the dynamic load and start the fatigue testing.

A4.3. Control during the test the magnitude of the applied force.

A4.4. Record the number of cycles applied.

A4.5. Record the number of cycles after which a crack is represented at the critical point.

A4.6. Continue the test to observe crack growth.

A4.7. Stop testing.

The specimen tested is physically representative of the upper right section of the front door frame of the truck, was welded by the MIG process and is made of rectangular shape, Fig. 7.

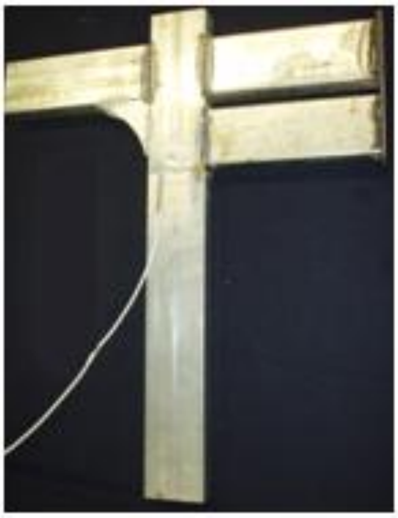

Figure 7: Test specimen of the bus structure

Fig. 8 shows the specimen placed in the fatigue machine and the loading device, which was used, a frame was constructed to be placed inside the testing machine.

Figure 8: Test specimen placed on the testing machine

III. RESULTS

Based on the methodology shown, it was possible to perform the fatigue testing on the structural section described in this research. The results obtained in the test performed on the specimen are shown in Table 1, and are valid for the location where a fatigue crack initiated in the specimen.

Table 1: Results obtained in the testing

Parameters	Test piece
Cyclic frequency	2 Hz
Load	350 Kg
Crack initiationcycle	15,000 cycles
Final testing cycle	40,000 cycles

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A crack was observed in the weld zone generated by the fatigue testing, which propagates on one side of the weld bead, the crack deviates towards the rectangular profile, where it grows in a relatively regular manner over a very considerable distance. Fig. 9 and 10 shows the fracture in the specimen physically representing the upper right section of the front door frame after the fatigue testing.

Figure 9: Crack resulting from the fatigue testing, right side of the specimen test

Figure 10: Crack resulting from the fatigue testing, left side of the specimen test

With the help of the software, we proceeded to locate stress concentration zones, finding that these zones coincided with the local regions of the failures. Figure 11 and 12 shows the simulation of the stresses in the specimen of structure with the load applied in the testing, where it can be seen that the maximum stress appears in the zone where the crack grow.

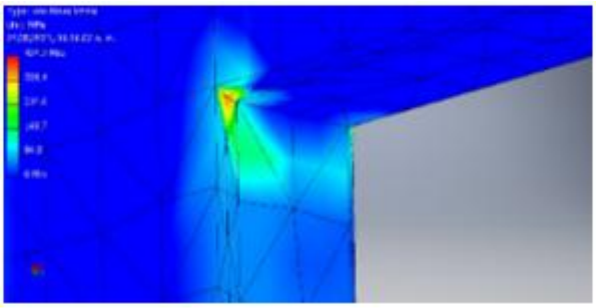

Figure 11: Simulation of stresses in the specimen (right side) at the place where the crack grow

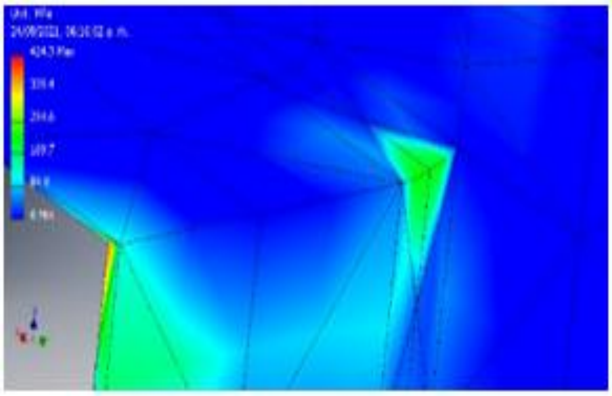

Figure 12: Simulation of stresses in the specimen (left side) at the place where the crack grow

IV. CONCLUSION

The use of a working methodology was decisive in the solution of the problem that was posed for the elaboration of this research. It should be emphasized that there is no reliable theoretical means to predict exactly when a fatigue crack will initiate. Instead, experimental testings must be performed to obtain information.

Crack propagation is highly dependent on the value of the maximum load to which the structural component is subjected. Sometimes it is not possible to know this load in its entirety; however, if the maximum stress in the component is known, it is possible to assume an approximate value.

Since it was not possible to testing the real structure, due to the lack of infrastructure, part of the structure was tested in fatigue testings. Due to the complexity and high cost of fatigue analysis in complete systems, it was essential to resort to laboratory testings on prototypes (specimens). Therefore, a simple specimen simulating the structural components was used.

It was possible to reproduce in a specimen in the laboratory by means of the experimental fatigue testing, in the section of the upper right corner of the front door frame, the crack initiation point and its growth, the specimen was tested until failure to obtain information on the total fatigue life of the component.

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