

## **Induce stress of the cracks in the chassis structure of the mobile crane used in constructions on any type of terrain**

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### **Abstract**

It was determined that at the mobile cranes used in constructions on any type of terrain (for instance, at Tadano Faun ATF 30-21 owned by SUT Carpati S.A.– Bucharest) there are some cracks in the structure of the 4x4x4 – type chassis with motor and driving wheels. The cracks in the welding seams as well as in its structure were determined for the first time during the oil changing in the gearing, in 2006; so they were mended by welding. After an year, in 2007, the chassis structure is presented here by photos and commentaries on the existing cracks. It is shown the mending solutions of the cracks made by SUT Carpati and those proposed by the manufacturer on the basis of the photos shot in 2006. The way they appear and the crack evolution in time are not known but it is quite sure they were done by the bad roads of the sites where the crane moves as well as by operating it by blocking the automatic control system of stress limiter which increases the induced efforts and stress value in the area and chassis structure as the crane operator does these to increase both the radius and the working height accepted by the limiter. Further, there are remarks on the cracking mechanics and crack dynamics; on the induced stress at crack peaks and cracking criteria for the elastic and elastic-plastic models. Some conclusions are drawn regarding the case shown and the way it must be mended.

### **1. Introduction**

During exploitation of the cranes used on any type of terrain (eg. Tadano Faun ATF 30-21 crane owned by SUT Carpati, Bucharest) there were detected some cracks in the transport chassis structure.

It is not known their evolution in time, but it is quite sure that they appeared because of the bad roads the cranes move as well as the blocking of their automatic control system of the stress limiter. Figure 1 and 2 show the ATF 30-21 crane that needs to have rebuilt the cracks in the chassis.



Figure 1



Figure 2

Note: The photos were shot by Dan Paraschivescu, diplomat engineer at SUT Carpati and by Alexandru Sarbu, third year student at the Faculty of Technological Equipment.

## 2. The characteristics of the investigated crane [1]

The telescopic arm mobile crane used on any type of road, investigated below has the following technical characteristics ATF 30-21 Tadano Faun model; telescopic arm length 8.6-28.5m; maximum height of hoisting hook – 42.0m; Euromat 2 engine; power 205kw (279 HP); transmission with power automatic crank ZF with lock-up; chassis running system; wheel numbers/motor wheel number/driving wheel number (4x4x4); total length – 9.98m; width – 2.55m; height – 3.32m; run mass – 24t.

**Maximum load** – 35t; lifted at an arm length of 8.6m, a radius of 2.7m, full rotation at 360 degrees and maximum counterpoise with a mass of 5.6t.

According to the load diagram for a radius of 26.0m and the maximum arm length of 28.5m a load of 1.1t is lifted. Among the load characteristics of the crane there are shown the telescoping degrees of the mobile sections noted in %, that is: per a mobile section of peak I, its extension may be of 50 and 100%; for the intermediate section II – 25, 50, 75 and 100% and per the mobile section III – 25, 50, 75 and 100%. Depending on the resistance of the arm structure there are different variants of telescoping for which significant changes appear in the load lifting capacity; that is for the same arm length the computer indicates the load that may be lifted depending on the characteristics of the crane resistance and stability.

**Trials on the two axes** – 12t, total transport mass – 24t

**Load traction force**, hoisting tackle-pulley, with 11 cable branch is of 32t and the pulley block mass is of 280kg. the lifting speed of the pulley keeps on varying between 0 and 120m/min, under load due to the action of the pump by the help of the crank that transmits the power from the engine which does not interrupt the transmission of the traction force under load. The maximum traction force on a cable branch is of 39 kw.

**Rotation speed is variable** 0-2.5 turns/min

**Angle of tilt** 1-80 degrees

**Arm telescoping time** 8.6-28.5m, about 75s

**Chassis frame** is a welded construction of steel having a high resistance with a fine grain.

**Telescopic settings** lean against 4 points being hydraulically driven. The base of the support polygon has the following dimensions: 6.28m (4.7m) x 6.35m, being possible two positions for the side extension of the settings .

**Engine:** Mercedes Benz – 6 cylinders, model OM 906 LA (Euromat 2, EPA 2) diesel cooled by water. Power 250kw at 2200 turns/min, moment of torsion 1100 Nm during the rotation interval – 1200-1600 turn/min

**Transmission:** with automatic transmission crane 610G 210 and fluid converter (with lock-up from the speed 1), forward cruising speeds and 1 backward cruising speed.

Velocity step number	1	2	3	4	5	6	R	Slope [%]
Maximum speed [km/h]	10	15	24	36	57	80	10	40
Minimum speed [km/h]	0-5	0-7	0-11	0-17	0-27	0-41	0-5	74

**Axis:** first driving and motor axis with limited slip differential. The second axis is identical with the first one

**Suspension:** air-hydraulic with control on the chassis.

**Brake assembly:** duty brake with double circuit, pneumatic with ABS. parking brake, activated by the spring, on the dees 1 and 2. Additional brake: mater brake on the diversion tunnel with a constant obstructing of the tunnel.

**Tires:** 1400R25

**Steering system:** with control from the ZF cabin, semi-block with 2 hydraulic circuits, mechanical system on the front axes and a hydraulic system with steering pump.

**Crane frame:** it is a welded structure of high resistance steel being very strong to torsion. The connection to the chassis is done through a ball rim that allow the superstructure to rotate 360°

**Hydraulic system:** it has 3 hydraulic diesel circuits consisting of double axial pump with small pistons hydraulically controlled with varying capacity, 1 triple pump with gear wheels. The pumps drive the move with a power of 195 km at 2000 turns/min (DIN 627-DB/DIN 6271)

**Control:** 2 joystick-type levers to simultaneously operate the hydraulic crane movement.

**Telescopic arm** has 4 arm sections. It is a construction with high resistance to stretch, made of fine grain steel consisting of a base fixed section and 3 mobile sections, extensible from 8.6m to 28.5m under a partial load.

**Tilting system:** 1 hydraulic cylinder with double action, built in brake and its own valve.

**Main pulley:** hydraulic engine with axial pistons, constant capacity that drives the pulley inside a built-in planetary reduction gear box, controlled by a multiple disk brake with free rotation.

**Rotation system:** hydraulic engine with constant capacity, two-stepped planetary reduction gear box, pedal-operated. It contains a parking brake too. Continuous adjusting speed 0-1.6 turns/min

**Standard counterpoise** 2.6t. It may be added another counterpoise, total mass of 5.6t

### 3. Analysis of the cracks in the chassis structure and their development

The chassis construction is made of two box spars, welded at the ends by the casing of the telescopic pressing on feet through gusset (Figure 3 and 4) on the back side of the crane, their cracked weldings being found in 2006.

Figure 5 shows the crack in the stiffener of the box spar from the back of the setting, as it appeared in 2006.



Figure 3



Figure 4



Figure 5

Figure 6,a shows the right back gusset and the Figure 6,b shows the left back gusset on the which one can see the real cracks in the weldings that set the chassis on the back setting casing( Fig.7,a and b). Figure 8 shows the crack in the gusset welding set the left box spare on the front crane casing.



a

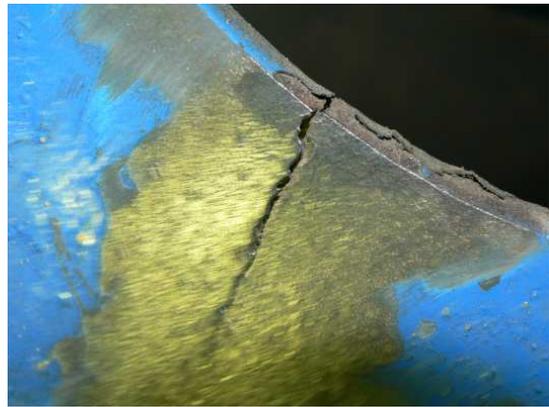


b

Figure 6



a



b

Figure 7

On the top, between the box spare housings a square plate is welded; it is cut at the middle which links the setting casing with the rotation crown support (see photo in Fig 5, and the carding system of the back deck in Fig 9). At this plate there are now a series of cracks (see Fig 10 and 11) that are arranged along the longitudinal axis and crosswise in the 4 points along the plate diagonals.



Figure 8



Figure 9



Figure 10



Figure 11

Other cracks are along the plate in set (see Fig 10). The most important are the u-shaped cracks that start sideways from the gusset base and part the longerons from the back pressing-on box casing (see Fig 6,a and Fig 6,b). Other cracks are on the left front side (see Fig 8). Here the cracks are in the horizontal welding seam of the u-shaped gusset. They show a split of the welding under the action of chassis bending during operating. The metallic construction is stiffened in the middle by a plate where the rotation crown is set, linking the superstructure with the chassis. The area where cracks appeared on the cut plate of the chassis is in front of the back motor deck (see Fig 5, photo 2006 and the Fig 10 si 11, photo 2007).

The area of the cracked plate on the general plan of the metallic construction is shown in Fig 12. On this plan the constructor, after the initial construction put strengthening ring shown in Fig 17.

Due to the counterpoises the structure of the rotating platform is always stressed. Additionally, the base of the telescopic arm is jointed with the superstructure in the same area on the vertical with back axis of the car.

The metallic structure of the chassis is stressed at:

- *Bending* under the action of the vertical loads of the hook load by the arm mass (whose load centre continuously changes during its telescoping, but at a maximum tilting angle a part of its mass is found on the back of platform rotating axis and it takes part in increasing the stability moment at small radii), as well as the rotating platform mass, engine mass, counterpoises, hydraulic acting systems, cabin, etc.

- *The torsion moment in the vertical plan of the chassis longerons* appears when the suprastructure rotates and reaches the maximum when the arm is cross on the chassis structure.

Additional to that it is the twisting moment that comes up crosswise the rotating axes of the superstructure, in horizontal plan, given by the centrifugal forces on the load, arm and counterpoise and by the wind action on their rotating surfaces. This moment evenly distributes along the linking plates between the longerons on the pressing-on box as well as on the plate that set the crown in the central area.

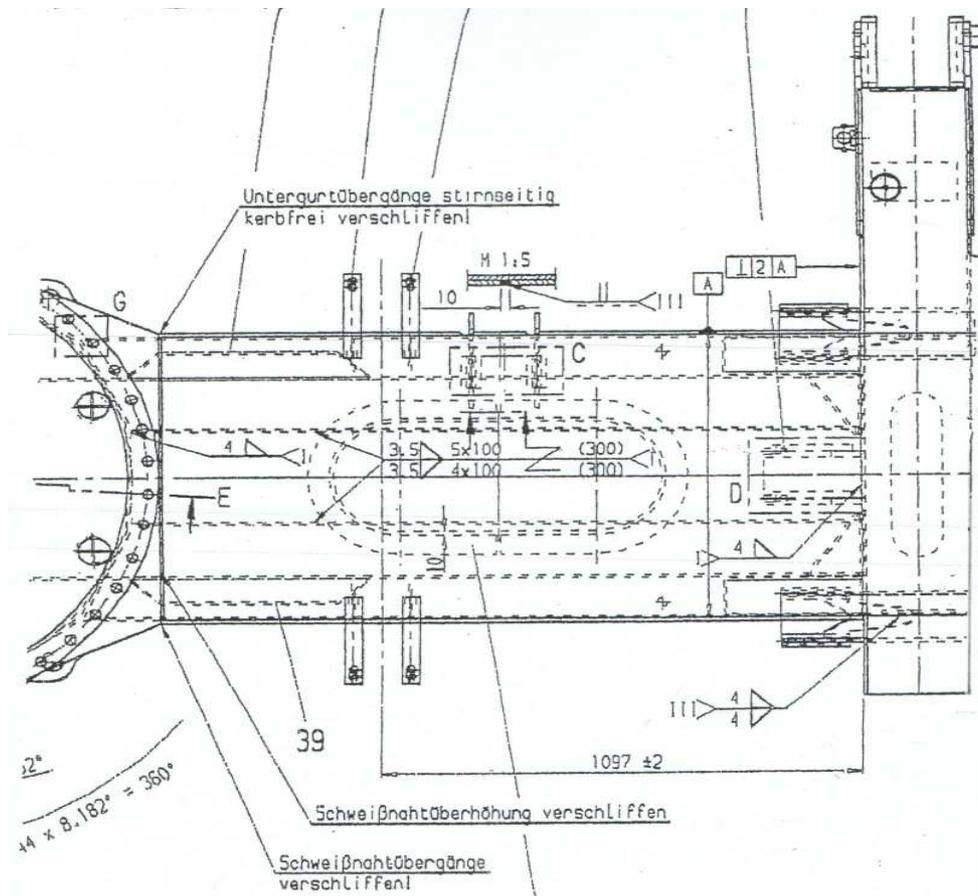


Figure 12[1]

The most stressed element where the cracks appeared, is the linked plate between the longerons built in its contour being cut inside. The cracks appeared due the plate bending in vertical plan and due the torsion on two directions (vertical and horizontal), (see Fig 5, 10 si 11) both in welding coordinates and its structure.

On the photos you can detect the type of the cracks that are according to the classical schemes of their appearance that is [2]:

a) Normal breaking of the weldings by their parting as shown in Fig 13; it corresponds to the cracks in the welding coordinates of the u-shaped gussets that connect them with the back box (Fig 6,a and 6,b) and front gusset respectively

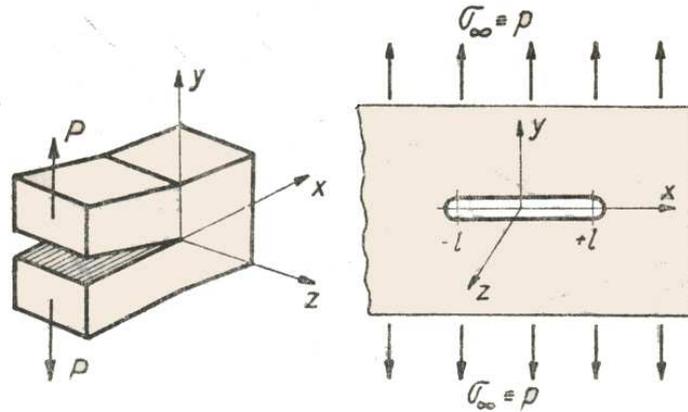


Figure 13[2]

b) The breaking of the welding and material by sliding due to the lateral shear shown in Fig 14. It can be seen at the basis of the u-shaped gussets (Fig 7,a and b) that are welded to the back pressing-on box casing

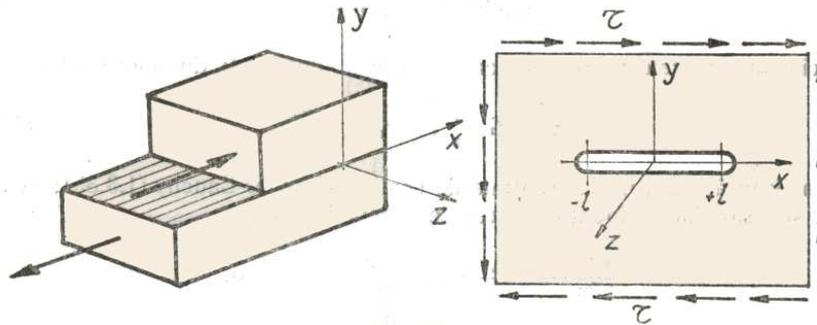


Figure 14[2]

c) The breaking of the welding and material by sliding due to the longitudinal shear shown in Fig 15. It correspond to the cracks in the plate (see Fig 7,b).

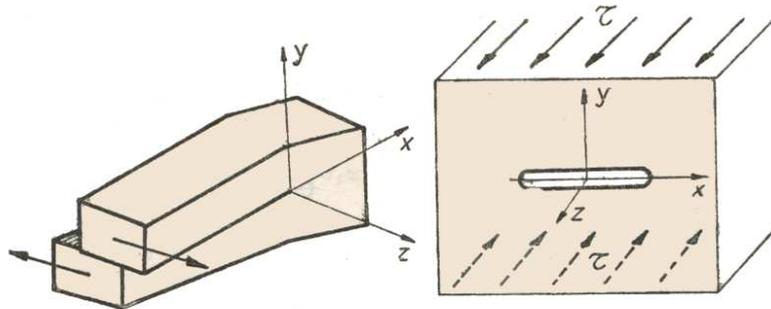


Figure 15 [2]

These cracks are made by the crane movements on the raw rough roads when, although the speed is very low, some different vertical reactions appear longitudinally and

laterally at the wheels as well as other traction-breaking forces in horizontal plan due to the chassis oscillations and its rotations in two directions, longitudinally and laterally, the movements on the vertical respectively changing the load centre of the chassis against that one of the superstructure. These situations lead to the appearance of some torsion couples and additional bending moments that act vertically, longitudinally and laterally or horizontally at the transport chassis level. These actions are transmitted to the narrow and high caisson of the chassis longerons that have their maximum elasticity in front of the back deck. To this stressed during the transport, there are some more: those that appear when the crane with a load in its hook moves on the site and those that appear when the crane operates with the load in its hook. Besides, the extension of the stocks in their working positions changes the state of the girders in stocks if the crane lifts the same loads.

From those mentioned above it results that the chassis structure supports combined stresses of bending and torsion that appear in many directions, their size overexceeding the allowed values when operating with the load limiter blocked.

As a consequence of the cracks in the chassis structure, the German constructor proposes the welding of a strengthening rib as a horseshoe of 7 mm in the cut area of the cracked plate (see Fig 12).

Another remark is that the crane mass in pressed-on state (24t own mass + 3t additional mass of the counterpoise). Smaller than the maximum load mass of 35t that may be lifted at a radius of 2.7m and minimum arm length of 8.6m.

This is possible by absorbing the bending and torsion moments at overturning generated by the arm load and mass reduced to the peak that are absorbed by the stability moment that appear against the overturning edge at stocks level given by the counterpoise action, a part of the arm mass (that is on the back of the rotating crown), chassis mass on the stock feet that form a supporting polygon of 6.35m x 6.28m.

Another aspect that has a contribution to the additional stress of the chassis is the possibility of the telescopic arm to lift different loads when working at the same lengths but in different telescoping variants of the sections. The solutions are chosen by the electronic computer of the crane or the operator's manual depending on the working necessities that so will overcharge the structure. In these conditions, if the electronic limiter is uncoupled it may be done operations with greater radius the allowed maximum value that cause the overloads to be transmitted to the unprotected construction elements, in their particular case to the chassis components where the possible faults existing as microcracks, the material non-uniformity, etc will increase in time through a cumulative effect.

Due to the appearance of some very big local efforts in the structure, the material becomes elasto-plastic makes the yield joints and local bending moments generated by the material flow. The value of these very big efforts may generate along the time the appearance of some fragile or quasi-fragile breaks in the metallic construction starting from the change of the stress state produced by the microcracks or other faults.

They represent strong bundles that disturb the homogeneity of the stress fields and creates local favourable conditions for the microcracks. This fact was detected from the development of the cracks too during a year, when they were monitored (Fig.7,a and b).

The studying the crack propagating conditions characterize the capacities to resist to material breaking, together with the multiple influential factor, and represent the main preoccupation of the breaking, together with the multiple influential factor, and represent the main preoccupation of the breaking mechanics in order to establish some criteria of designing or cheking to take into account the unavoidable existence of the crack-type faults.

#### 4. Elements of breaking mechanics and crack dynamics [2]

Por the space with the cracks subject to longitudinal shears, analysed by a calculus pattern as that one shown in figure 16,a and b where the crack of  $2l$  length is surrounded by a contour  $C$ ; an isolated crack point placed outside the contour is taken into account (see Figure 16 a). For this case, under the point [2] the index  $K$  is indicated called stress intensity coefficient, representing a distribution characteristic of the stresses near the crack peak during its propagation (it must not be mistaken with the like factors from the stress bundles).

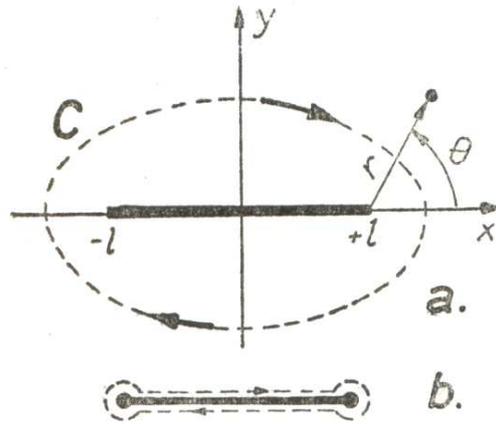


Figure 16 [2]

For a piece with a given geometry, the coefficient  $K_{III}$  depends on the given tangential stress. If this is constant we get:

$$K_{III} = \tau \sqrt{\pi \cdot i} \quad (4.1)$$

So, in order to clarify the stress behaviour near the crack peak, in case of cracked space subject of the longitudinal shear we use

$$\begin{aligned} \tau_{xz} &= -\frac{K_{III}}{\sqrt{2\pi r}} \sin \frac{\theta}{2} \\ \tau_{yz} &= \frac{K_{II}}{\sqrt{2\pi r}} \cos \frac{\theta}{2} \end{aligned} \quad (4.2)$$

For the homogenous traction field  $\sigma_y = \sigma_\infty = p$  applied at the edge of the of the crack  $\sigma_{xy} = 0$ ,  $\sigma_y = -p$  (more generally  $\sigma_y = -p(z)$ )  
 For the cracked space subject to traction the following calculus relations result [2]:

$$\begin{aligned}\sigma_x &= K_I \frac{\cos \frac{\theta}{2}}{\sqrt{2\pi r}} \left( 1 - \sin \frac{\theta}{2} \sin \frac{3\theta}{2} \right) \\ \sigma_y &= K_I \frac{\cos \frac{\theta}{2}}{\sqrt{2\pi r}} \left( 1 + \sin \frac{\theta}{2} \sin \frac{3\theta}{2} \right) \\ \tau_{xy} &= K_I \frac{\cos \frac{\theta}{2}}{\sqrt{2\pi r}} \sin \frac{\theta}{2} \cos \frac{3\theta}{2}\end{aligned}\quad (4.3)$$

And the movements:

$$\begin{aligned}U &= \frac{K_I}{G} \sqrt{\frac{r}{2\pi}} \cos \frac{\theta}{2} \left( \frac{\Lambda - 1}{2} + \sin^2 \frac{\theta}{2} \right) \\ V &= \frac{K_I}{G} \sqrt{\frac{r}{2\pi}} \sin \frac{\theta}{2} \left( \frac{\Lambda + 1}{2} - \cos^2 \frac{\theta}{2} \right)\end{aligned}\quad (4.4)$$

Within the relations (4.3) there are neglected the terms that have finite values at the crack peak; in case of flat deforming the stress state at the crack peak is generally near the stress field from the hydrostatic traction such favourizing the fragile breaking.

The cracked space subject to the lateral shear represents the case of the pattern II of propagating the crack that may be solved by setting above the homogenous shear field the state made by the action of the stress on the crack edges.

$$\sigma_y = 0 \quad \text{și} \quad \tau_{xy} = -\tau \quad (4.5)$$

Within a small neighborhood of the crack peak  $r < 1$  we get  
 With the deforming

$$\begin{aligned}\sigma_x &= -\frac{K_{II}}{\sqrt{2\pi r}} \sin \frac{\theta}{2} \left( 2 + \cos \frac{\theta}{2} \cos \frac{3\theta}{2} \right) \\ \sigma_y &= \frac{K_{II}}{\sqrt{2\pi r}} \sin \frac{\theta}{2} \cos \frac{\theta}{2} \cos \frac{3\theta}{2} \\ \tau_{xy} &= \frac{K_{II}}{\sqrt{2\pi r}} \cos \frac{\theta}{2} \left( 1 - \sin \frac{\theta}{2} \sin \frac{3\theta}{2} \right)\end{aligned}\quad (4.6)$$

Where  $\Lambda = 3 - 4\nu$  (for the flat state of deforming)

$$\Lambda = \frac{3 - \nu}{1 + \nu} \quad \text{for the flat state of stress}$$

At the analysed problems the stressed near the crack peak have singularities in the shape of  $k/2r$ , and the movements tend to zero like  $\frac{K_i}{G} \sqrt{\frac{r}{2\pi}}$ , where by  $K_i$  ( $i=I, II, III$ ) it was

noted the coefficient of stress intensity depending on the load that characterizes the energy flux towards the peak that is released when the welds parts, shown in Figure 13, 14, and 15.

The obtained solution were about the square cracks in infinite bodies. Instead, the deducted relations (4.1-4.7) will characterize the behaviors and movements of the stresses near the edges of some holes of any form if by  $r$  it is understood the distance from the normal to the crack contour (fig 16 a).

The study of the energetic balance conditions clears into a general context, the crack propagation. By passing from the state 1 to the state 2, the hole volume it will increase with DV; the surface will change with.

The balance equation will base the following form:

$$\Delta U + \Delta K = \Delta A + \Delta Q - \Delta \pi \quad (4.8)$$

Where:  $\Delta U$  – elastic energy variations  
 $\Delta K$  – kinetic energy variation  
 $\Delta A$  – mechanical work variation of external forces  
 $\Delta Q$  – heat flux  
 $\Delta \pi$  – energy flux provoked by some thing else but only the energy spent for breaking is taken into account.

On the hypothesis of small deforming (quasi-static) it may be neglected both the kinetic energy variation and the heat flux:

$$\Delta U - \Delta A = -\Delta \pi \quad (4.9)$$

Where  $U - A = W$  denotes the potential energy of the body; so

$$\Delta W = -\Delta \pi \quad (4.10)$$

It results that it is necessary to compute the potential energy variation of the body during the process of crack enlarging. Taking into account the fig 16 a, near the crack peak it is obtained:  $\theta = \pi, r = \Delta l - x = \Delta l(1 - \zeta)$

- For slot plan traction

$$\Delta W_I = -\frac{K_I^2}{8G}(\Lambda + 1)\Delta l \quad (4.11)$$

- For cross wise shear

$$\Delta W_{II} = -\frac{K_{II}^2}{8G}(\Lambda + 1)\Delta L \quad (4.12)$$

- For longitudinal shear

$$\Delta W_{III} = -\frac{K_{III}^2}{2G}\Delta l \quad (4.13)$$

For the crack to enlarge it is necessary to overcome the linking forces between the particles of the atom network in material both the normal and the lateral ones. According to Griffith the dislocation energy is equal to:

From the relations:

$$\Delta\pi = 2\gamma \cdot \Delta\Sigma \quad (4.14)$$

$$\gamma > 0, \quad d\pi = 2\gamma \cdot \Delta l \quad (4.15)$$

$$\frac{K_I^2}{8G}(\Lambda + 1) = 2\gamma$$

From:  $\frac{K_{II}^2}{8G}(\Lambda + 1) = 2\gamma \quad (4.16)$

$$\frac{K_{III}^2}{2G} = 2\gamma$$

And  $p(\xi) = \text{constant}$ , it results Griffith's formula

$$p^2 = \frac{2E\gamma}{\pi l(1-\nu^2)} \quad (4.17)$$

dW is calculated after stress state – deforming in the crack peak that has there a singularity. Through the crack peak the system energy flows; this energy is spent in this area to destroy the material. In the crack peak the small deforming conditions and Hooke's law are not satisfied [2]

## 5. Breaking criteria for elastic and elastic-plastic patterns

At the correctly designed and sized constructions the crack development is stable at the beginning, the crack sizes enlarging together with the stress increasing. This means that if it is ensured a stable crack enlargement to the variation interval, the resistance characteristic will depend in fact on the initial sizes of the crack

$$K = \sqrt{\frac{2\gamma}{c}} = K_0 \quad (4.18)$$

Represents the Irwin's formula that replaces the Griffith's global energetic criterium with some "force" conditions on the crack peak. So, the  $K^2/G$  ratio may be treated as a crack extension force. The crack starts propagating when the force K attains the value  $k_0$ , the characteristic of the given material the breaking criterium having a local character in this case. The two criteria (4.16) and (4.17) are equivalent, the Irwin's one being easier as the analyses is done near the crack peak and according to the corresponding intensity of the stress state. Usually, it is tested a plate specimen with a central crack where under subcritical regime, it is measured the increasing of the crack length together with the stress increasing. These data allow  $k_0$  to be determined.

In case of big plastic deforming as those meet in this case, it is very difficult to obtain correct values at the crack peak.

## 6. Conclusions

1. It must obey the strict rules of preparing the material and welding in argon medium as the manufacturer imposed, using the admixture material indicated by him, followed up by the stress relaxation of the weldings done
2. The affected areas stiffening is done with strengthening U – shaped elements built according to the hole curve in the plate indicated by the manufacturer (shown in Fig 17) having a depth of 7mm in order to eliminate the enlargement of the crack made by the stiffening; otherwise the crack development will go on in this area.
3. The corners welded inside the longerons together with the plate (see Fig. 9) in order to ensure a greater rigidity of the chassis in this zone, did not solve the problem as they were applied without a preliminary preparation of the material. The cracks still appeared both on the end weldings of the U-shaped gussets that stiffen the chassis with the back and front casing and the material of the analyzed plate. The cracks developed in the plate are in the same position as before, i.e.: after the longitudinal and cross axis, simetrically in 4 points on the diagonal axes of the plate (see Figures 9, 10 si 11)

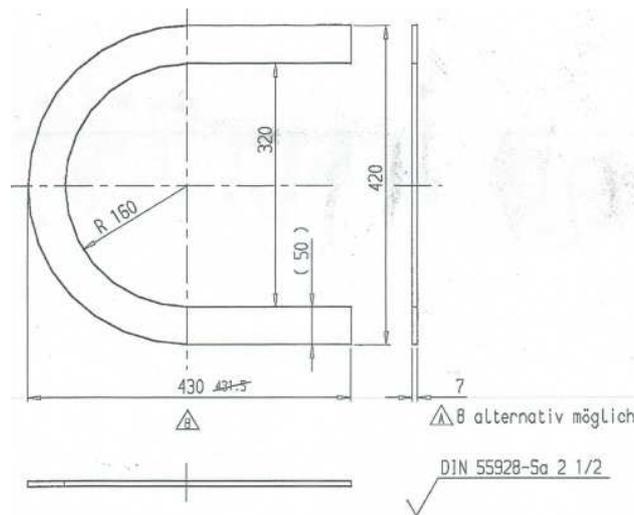


Figure17[ 1]

4. The cracked plate between the longerons and the web of the rear support which is also cracked along the gusset ( see Fig.7,a) they will be removed from the construction and will be replaced with the plates according to the project.

## Bibliography

1. **Cartea macaralei Tadano Faun All-Terrain ATF 30-2L**, ISO 9001 + planse pentru sasiu cu nervuri de intarire.
2. **Boleteanu, L., Dobre, I.** – Aplicatii ale mecanicii solidului deformabil in constructia de masini, Editura Facla, Timisoara 1978
3. **Sarbu, L., s.a.** – Masini de ridicat in constructii, exploare intretinere, reparare, Editura Tehnica, Bucuresti. 1989.