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Dynamic Amplification of Railway Bridges through Field Measurements and its Effect on Fatigue Damage

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Chapter 1

Introduction

1.1Introduction

Over the years, different types of train vehicles have been manufactured and, in addition, a large variety of railway bridge structures have been constructed. Monitoring and management of different bridge elements is vital issue to understand the real behaviour of structural which will assist towards more effective decision-making. There was a significant demand on understanding the dynamic performance of railway bridges and this has increased in recent years. Fatigue damage assessment of steel railway bridges is one of the most popular subjects in the literature and several papers proposed methods to carry out the most efficient and more effective procedure for fatigue damage calculation. Estimating the actual dynamic response and determination of the real dynamic magnification factor (D.A.F.) for railway bridges may be complicated and challenging because of the several bridge members with different sections, size and direction. An approach for determining the most reliable dynamic amplification value is very important. Obtaining the most reliable dynamic magnification factors leads to better estimation of remaining fatigue life and provide the most economical fatigue assessment.

The first section of this dissertation will be an introduction which covers the summary of the other chapters and the different methods of calculation will also be described briefly. In addition, the main aims and objectives of the dissertation will be introduced. The second chapter is the literature review which provides the definition of the dynamic magnification factor. In addition, a number of previous studies regarding dynamic magnification factors and dynamic behaviour of railway bridges will be summarised. Moreover, two code recommendations for calculating dynamic factors will be presented. Another part of this section will explain different methods for calculating fatigue damage in railway bridges.

The case study is presented in the third chapter. The first section of the chapter describes the bridge used in this study. The second section will explain the field measurement program methods for data collection from the bridge and the way of monitoring and the tools that have been used during monitoring and the data acquisition system. The fourth chapter of this dissertation will present the results and discussions. The first section of this chapter will provide the field measurement data of the bridge. The second part will present the dynamic magnification factors of the bridge estimated through the available field measurements, Calculation of the dynamic implications by using Euro code 1 recommendations will be shown in section three. The fourth and fifth part of the chapter will cover calculation of D.A.F by using the Network Rail (NR) bridge assessment code equations and the comparison between the three pre-mentioned results respectively.

The calculation of fatigue damage by using N-R curves using four different methods will be provided in fifth chapter. First the damage will be calculate by using dynamic responses data, secondly the damage will be obtained by magnifying the static damage using the three pre-calculated D.A.F in chapter four. Appropriate data tables will be prepared to compare and discuss the results. The sixth chapter will be the final section of this study that covers the conclusions and suggestions for future study.

1.2 Objective of the study

The main purpose of this research is to calculate the most realistic dynamic magnification factors for a case study bridge in Sweden, based on the recorded field measurements available for that bridge. The measurements have been carried out during train passages with different velocities (1km/hr(static), 51 km/hr, 52km/hr and 82 km/hr). Another aim of this study is to compare the calculated dynamic magnification factors with the ones obtained by bridge code recommendations. In this case, two different codes which are most widely used in the U.K and Europe, i.e. Eurocode 1 and the NR assessment codes, have been considered. In addition the actual fatigue damage will be calculated and compared with the damages obtained through the use of the calculated dynamic magnification factors with static stresses.

1.3 Methodology

This section provides a summary of the methods that will be used to calculate the dynamic magnification factor of the bridge at different points for a given span. Undoubtedly, there are several methods of calculation of dynamic amplification factors. One of the most common methods is creating a finite element model for the train and using numerical the direct integration method; the other method is creating a finite element model in a software and calculate the deflection due to moving loads. These methods are recommended by a number of researchers but they assume train axles as moving point loads. In this dissertation, field measurement data is used to obtain the most realistic dynamic magnification factors.

The collected data from field measurement was massive and recorded under different train speeds; in this dissertation the data for velocities of 1km/hr, 51km/hr, 52km/hr and 82km/hr have been used. MATLAB software will be used to re-arrange the large amount of data and convert strains into stresses by multiplication by the Modulus of Elasticity of 200 MPA. Then for every recorded single point on different members, the dynamic amplification factors were calculated considering the maximum stress response of the point. Following, an Excel spread sheet has been created to obtain the dynamic magnification factors using EUROCODE 1 and NR code recommendations. Finally a typical special spread sheet was used to obtain stress ranges from the stress histories by using the rain flow counting method and another spread sheet has been created to calculate fatigue damage based on the S-N curve method.

Chapter 2

Literature Review

2.1 Dynamic Amplification Factor (DAF)

Undoubtedly the number of train passages over bridges is rising in modern traffic as a result of population growth worldwide. The number of railway bridges constructed has increased since the beginning of last century. In the United Kingdom most of railway bridges are constructed from steel which is considered as one of the metals most subjected to fatigue damage. That leads to increased importance of and interest in the consideration of dynamic effects of trains on railway bridges during the train passage. In addition the speed increment of trains as well as increasing the axle loads makes the checking of bridge member safety more significant in order to estimate the quantity of dynamic effect on bridges and consider it during design and assessment (Marques et al. 2009).

Traditionally, the calculation of fatigue damage has been carried out by increasing the static stresse by multiplying with specific dynamic amplification factors obtained from the codes (Liu et al. 2012). A dynamic amplification factor can be defined as the ratio of the absolute dynamic response to the absolute static response (fig 1). In the past, while assessment of steel bridges considered the speed of the train, it did not consider the increasing of fatigue damage due to resonance of the bridge while the train crosses it. This may cause over or under estimation of fatigue life of bridges that may lead to uneconomic assessment or replacement. Therefore, the analysis of actual/real damage in the case of fatigue assessment is a vital issue.

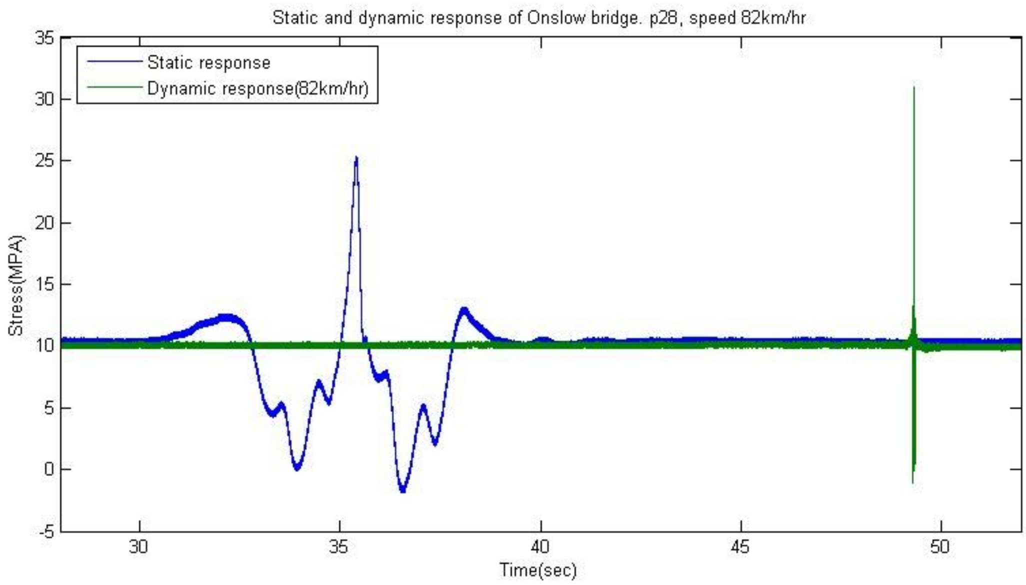


Figure (1) The difference between static and dynamic response of a bridge detail.

2.2 Previous studies:

Although there are a number of research papers and a number of different calculation methods regarding the dynamic performance of railway bridges, there are limited studies on obtaining more accurate dynamic amplification factors through field measurements. In this section, the previous studies and different methods of calculation of dynamic factors and fatigue damage are briefly described.

The problem of dynamic magnification factor has been found in the 19th century by Paulter et al. (1991) and Willis (1849) carried out laboratory tests on cast iron beam models. Following that, several efforts has been done in order to investigate that problem. It was believed that the American Society of Civil Engineering (ASCE) published the first most important paper in 1931 regarding this problem. They made some recommendations based on the data collected from field measurements and they concluded that there is a difference between the bridge deck dynamic response and longitudinal members, therefore they suggested different magnification factors for each. Ruiz-Teran and Aparecio (2006) used the vibrational method to calculate the dynamic amplification factor of cable stayed bridges. In their paper they concluded that the dynamic amplification factors might be larger than 2 for sudden applied loads to the system. They therefore stated that the guidelines for calculation of DAF for cable bridges is under estimated because it provides the value of 2 as the upper limit, hence they suggested that it should be revised. Also, they suggested to carry out new research depending on different internal forces in conventional cable stayed bridges to calculate DAF in order to use them as the base of guidance for the design.

Enochsson and Elfgren (2008) carried out a study regarding increasing loading carrying capacity of the Haparanda railway line in Sweden from 22.5 tons to 25 tons. They calculated dynamic magnification factors for five existing railway bridges; the Kerasjokk bridge has been chosen to monitor the toughness, deflections through strain gauges and assessment. They calculated the dynamic amplification factors using code recommendations and they also developed a finite element model for the bridge. It was concluded that the dynamic amplification factors obtained from measurement are slightly lower than those obtained from the model and codes. They have decided to consider the magnification factors obtained from strain gauges as the actual ones. It was stated that the fatigue capacity of the floor beams are under estimated, therefore they decided that the bridges can carry an axle load more than 250 KN.

Lee et al. (2011) carried out analysis of bridges under moving trains as a beam and moving masses model in order to get the most reasonable dynamic magnification factors for fatigue assessment of short simple railway bridges in Korea. In their calculations they considered the stiffness, span length of the bridge, the type and speed of trains as the most significant factors. They compared their results with the Korean code recommendations and they found that the code overestimated the DAF values in terms of fatigue assessment. They recommended only 50% of impact factor to be used for design instead of 65%. In addition, it was found that very short simple bridges with spans not exceeding the maximum axle spacing are more subjected to fatigue damage. Furthermore they showed that the dynamic magnification factors for such bridges can rise with free component vibration.

In order to examine the structural behaviour and fatigue assessment of the Trezoi bridge, Marques et al(2009). have carried out a finite element analysis by using the SOLVIA software. In addition, they established a numerical model by comparing with the field measurements. Fatigue damage of the bridge has been calculated using the fracture mechanics concept and damage accumulation method; they showed that the results in both situations are similar and they found that the annual traffic growth has a great impact on increasing fatigue damage to higher levels.

Liu et al. (2009) prepared a paper in order to investigate the impact of train interaction with bridge on the dynamic response of the bridge and dynamic amplification factors. A finite element model analysis was carried out in order to calculate the effects of significant parameters such as resonance, damping, the ratio of natural frequency of the train to that of the bridge and the speed as well as the mass of the train. They concluded that the dynamic amplification value peaks while the vehicle passage produces resonance similar to the bridge. In addition they showed that the dynamic magnification factor is reduced due to increase in the natural frequency of the train. The greatest reduction will happen when the natural frequency of the train is slightly higher than the bridge one. Furthermore it is stated that the dynamic interaction increased with increasing train to bridge mass ratio.

Zhou et al. (2012) has carried out dynamic tests for high speed trains passing over composite railway bridges. They prepared a finite element model for the single span of the Sesia viaduct in Italy and examined six types of structural details in the bridge in order to find the most critical point for fatigue damage. They used the S-N curve and Palmgren Miner rule in combination with rainflow counting to obtain fatigue damage results. They concluded that the dynamic fatigue damage of each detail can be as twice as the static for a single train passage. In addition they determined the load carrying fillet welds around the gusset plate of the diagonal bracing as the most critical points for fatigue damage.

Another study has been made by Gu et al. (2008) in order to calculate the dynamic impact on railway bridges by using code recommendations as well as finite element analysis. The bridge over the M25 (structure ID :VTB2 93B) was chosen to analyse by simple hand calculations. Finite element model and direct integration method was used to obtain eigenvalue buckling modes. The analysis has been created under 145km/hr and 90 km/hr train speeds and the result was dynamic impact value was found equal to 1.211.They stated that the dynamic amplification factors and fatigue damage obtained by direct integration method is more reliable than code equations.

Ajka and Hartnett (2007) carried out a study regarding determining the effect of speed and damping on the dynamic response of bridges and dynamic amplification factors. They prepared a versatile numerical model for that purpose. Three dimensional finite element model was created and they used direct integration method for solving the equations of motion. It was concluded that the magnitude of dynamic magnification factor is increased due to increase in velocity, nevertheless they showed that this trend is not regular and in some points it can be fluctuating. In addition they showed that the dynamic amplification factors will be increased with increasing mass parameters but up to a speed parameter of 0.25 other trend might be downwards.

Marjka and Hartnet (2009) established a research paper to examine the response of an existing railway bridge during the train passage. Their investigation was based on the effect of random train irregularities and the bridge skewness on dynamic behaviour of the bridge.

They developed a dynamic bridge interaction model, obtained dynamic magnification factors based on displacements and made a comparison with current code recommendations. The bridge which was analysed was simply supported and made of wrought iron. Several trains including both passenger and freight trains were passed over the bridge with different velocities. The dynamic amplification factors for displacement were calculated and were found not being more than 10% and this compared with EN1991-2 which was almost 2.5%. Finaly they found that the skewness results in an increase in fundamental frequency. This lead to a shift in the dynamic amplification factors towards higher speeds.

Hamidi and Danshjo (2010) carried out a study to investigate the impact of train velocity, the number of axles, the distance between them and the length of bridge span on the dynamic amplification factors and compare them with code recommendations.

The dynamic response of four bridges with 10, 15, 20 and 25 meters span were calculated under train speed ranging between 100 to 400 km/hr speed with an axle distance of 13 to 24m. In their research, they showed that the calculated dynamic factors from their model in most cases were higher than the code recommendation. In addition, they claimed that there was a large increase in dynamic magnification factor values with increasing train velocity.

Furthermore, they found that the change in axle distance to span ratio has a considerable impact on dynamic magnification factors .

Leander et al. (2009) conducted research to report the result of inspections on a bridge in central Stockholm and compare them with the theoretical expectations. The main purpose of the study was fatigue crack assessment and determination of the remaining fatigue life of the bridge. It was found that there was not full agreement between the stress ranges obtained from true data through field measurements and the theoretical values. It was concluded that the service life of the bridge is well passed although they found some cracks in the main girders. It was believed that more inspection was needed to detect fatigue cracks on transverse beams and stringers. Finally they made several monitoring procedures to keep the bridge in service. A large amount of data was collected to use as a base for further research and some strengthening was decided for the bridge.

The research carried out by Imam et al. (2006) was in order to find a more efficient procedure to calculate more reliably the fatigue life for old riveted rail bridges. They have made a finite element analysis of a typical riveted rail bridge in UK. The impact of several parameters on fatigue damage were examined such as dynamic magnification factors, Young's Modulus and the fixity of the connections as well as classification of fatigue details. It was shown that the connections of stringer and cross girder were critical in terms of fatigue damage. In addition it was found that the fatigue damage of connections will be increased with increasing axle loads.

Moreno Delgado and dos Santos (1997) have made a research paper to show the effect of mass and stiffness of the bridge, the stiffness of the train as well as track irregularities on bridge dynamic response during passages. They found that the impact of stiffness and track irregularities on the dynamic response was very significant. It was concluded that more flexible bridges had higher dynamic magnification factors than rigid bridges; also they stated that the roughness of the bridge had considerable impact on dynamic amplification values.

Song et al. (2003) proposed a three dimensional finite element model in order to investigate the impact of train-bridge interactions on dynamic response of bridges. They analysed a simply supported composite bridge and they carried out a comparison between obtained dynamic magnifications with previous research and experimental values. It was found that the dynamic amplification factors obtained from their analysis exceeds the design code recommendations. Furthermore they showed that the speed and train irregularities have considerable effect on dynamic magnification factors.

Khadri et al. (2013) developed a vehicle-bridge model to investigate the consequence of several parameters on bridge dynamic magnification factors. It was concluded that the effect of roughness on dynamic response of railway bridges is significant and it was also shown that the discontinuity of a rail causes increase of dynamic magnification factors. In addition the most critical positions of rail discontinuity were determined as L/12 and L/4 where L is the span.

Herwig and Bruhwiler (2011) have written a paper regarding the effect of running train on dynamic response of bridges and fatigue damage. The field measurements of one track railway bridge have been used to examine the dynamic behaviour of the bridge and calculate more realistic dynamic amplification factors. It was shown that the train irregularities have a vital effect on dynamic magnification factor values. In addition it was found that the train velocity has a significant impact in terms of fatigue damage.

Cheng et al. (2001) investigated the effect of train structure on the dynamic response of bridges. A special model was prepared in order to examine the interactions between the track and the railway bridge. The moving train was modelled as a series of two degree of freedom mass spring damper system instead of wheel positions and a lower beam element was proposed to represent the bridge. The two models connected by a series of mass spring dampers to model the rail bed. It was found that the impact of the track structure on the dynamic response of the bridge is not considerable nevertheless the effect of bridge structure on the track dynamic response is significant.

Another research study was carried out by Bjorklund (2004) to explore the dynamic characteristics of an existing railway bridge under high train passage over 200km/hr. The finite element model of the bridge was developed by the LUSAS software and the train passage was assumed as constant and represented by moving axle loads. Parameters such as track irregularity and bridge-train interactions were neglected in the analyses. The speed of the train was considered as the most significant parameter affecting the dynamic performance of the bridge. It was concluded that the dynamic magnification will be increased due to an increase in train velocity and it peaks several times between 20km/hr and 300km/hr. In addition it was shown that the maximum resonance will occur in the middle of the bridge however the critical position for optimum dynamic amplification factors will be the edges. Furthermore, it was stated that bridge with higher density peaks dynamic magnification factors with lower train speed than the lower density ones.

2.3 Code recommendations for calculation of D.A.F

This section will present the equations provided by two bridge codes, Eurocode 1 and the NR assessment code.

2.3.1 Eurocode 1

BS EN 1991-2000 part 2 which is about "Actions on structures, Traffic loads on bridges" has created a set of equations regarding dynamic amplification factors of railway bridges. Annex D of the code has the equations for calculation of D.A.F for fatigue purposes. According to this code the dynamic magnification factors for each real train regarding fatigue assessments can be calculated by the following equation: 1+1/2(φ̀ + 1/2 φ̏) (D1)

The values of φ̀ and φ̏ can be obtained by these equations bellow.

$$\varphi' = \frac{K}{1 - K + K^4} \qquad \text{(D.2)}$$

with

$$K = \frac{v}{160} \qquad \text{for } L \leq 20\text{m} \qquad \text{(D.3)}$$

$$k = \frac{v}{47{,}16 L^{0.408}} \qquad \text{for } L > 20\text{m} \qquad \text{(D.4)}$$

and

$$\varphi'' = 0.56 e^{-\frac{L^2}{100}} \qquad \text{(D.5)}$$

where:

v is the maximum speed of the vehicle permitted (m/s)

L is the determinant length L_Φ in meters which can be calculated according to clause 6.4.5.3 as follows:

1- Determinant length can be obtained from table 1(6.2 of Eurocode 1.)

2- If the value of L_Φ is not present in table 1(6.2in Eurocode1) the code recommends the influence line of deflection of an element as L_Φ or alternative values should be provided .

3- If the stress history of a particular member of the bridge depends on several effects, each which regarding a certain structural behaviour, then each effect should be calculated due to suitable determinant length.

Table 1 (6.2 in the Eurocode 1) - Determinant Lengths (L_Φ)

Case	**Structural element**	**Determinant length L_Φ**
Steel deck plate: closed deck with ballast bed (orthotropic deck plate) (for local and transverse stresses)		
	Deck with cross girders and continuous longitudinal ribs:	
1.1	Deck plate (for both directions)	3 times cross girder spacing
1.2	Continuous longitudinal ribs	3 times cross girder spacing
	(Including small cantilevers up to 0.5m)a	
1.3	Cross girders	Twice the length of the cross girder
1.4	End cross girders	3.6m
	Deck plate with cross girders only:	
2.1	Deck plate(for both directions)	Twice cross girder spacing + 3m
2.2	Cross girders	Twice cross girder spacing + 3m
2.3	End cross girders	3.6m (b)
Steel grillage: open deck without ballast bed(b) (for local and transverse stresses)		

3.1	Rail bearers:	
	- as an element of a continuous grillage	3 times cross girder spacing
	- simply supported	Cross girder spacing + 3 m
3.2	Cantilever of rail bearer	3.6 m

Table 1(6.2 in the code) (continued)

3.3	Cross girders (as part of cross girder/ continuous rail bearer grillage)	Twice the length of the cross girder
3.4	End cross girders	3.6 m(b)
a In general all cantilevers greater than 0.5m supporting rail traffic actions need a special study in accordance with 6.4.6 and with the loading agreed with the relevant authority specified in the national annex. b It is recommended to apply φ3		

2.3.2 NR code recommendations

The network rail code NR/GN/CIV/025 clause 4.3.2.2 to 4.3.2.4 provides a set of equations to calculate the dynamic amplification factors for railway bridge members including factors related to fatigue assessment. Clause 4.3.2.2 of this code deals with the calculation of DAF for longitudinal members using table 2 (table 4.5 in the code) as follows:

Table 2 Dynamic amplification factors for longitudinal members(table 4.2 in the code)

	Dynamic Increment φ for bending	Dynamic Increment φ for shear
Normal track maintained for permissible speed ≤ 100mph	$\varphi_1 + \varphi_{11}$	

Track maintained for Permissible speed >100mph-125mph	$(\varphi_1 + \frac{\varphi_{11}}{2})$	2/3 x φ for bending
Fatigue calculation only	$0.5\,(\varphi_1 + \frac{\varphi_{11}}{2})$	

$\varphi_1 = \dfrac{K}{1-k+k^4}$ representing inertial response of the structure equation (D.6)

$k = \dfrac{v}{4.47 L\phi n_o}$ equation (D.7)

$\varphi_{11} = \alpha[56e^{(-\frac{L\phi}{10})} + 50(\frac{Ln_o}{80} - 1)e^{-(\frac{L\phi}{20})^2}]$ but ≥ 0 equation (D.8)

where :

α= 0.0002 v but ≥ 0.02 equation (D.9)

where:

L_Φ is the determinant length in meters obtained from table (3) (table 4.6 in the NR code)

L is the member span centre to centre from supports in meters

n_o is the fundamental natural frequency in Hertz of the structural member .

v is the speed in mph

Table (3) Determinant length (table 4.6 in the NR code)

Element	**Determinant Length LØ**
Steel and Wrought Iron	
Deck plate	
Discontinuous spanning longitudinally	Twice cross girder spacing + 3 meters
Discontinuous spanning two ways	Three times cross girder spacing
Continuous over ribs or stringers	As for 4 pan continuous beam
Rail Bearers	
Continuous	3 times cross girder spacing
Simply supported	Cross girder spacing + 3 meters

The natural frequencies (n_o) can be calculated using equations (4.6 to 4.8) in clause 4.3.2.3 in NR code as follows:

High frequencies (HF) $n_o = 94.7L^{-.748}$

Equation (D10)

Low frequencies (LF)

$$n_o = \frac{80}{L} \quad \text{for} \quad 4 \text{ meters} \leq L \leq 20 \text{ meters} \qquad \text{Equation (D.11)}$$

$$n_o = 23.58L^{-0592} \quad \text{for} \quad 20\text{m} < L \leq 100\text{meters} \qquad \text{Equation (D.12)}$$

The dynamic amplification factors for transverse beams can be calculated according to clause 4.3.2.4 of NR code. The code provides three equations to calculate D.A.F , the parameter of speed and the direction of a member according traffic is considered as shown in table 4.

Table 4 dynamic increment value (table 4.5 of NR code)

	Dynamic increment φ_T for bending	Dynamic increment fo φ_T r shear
Normal track maintained for permissible speed ≤100mph	0.008v	
Track maintained for permissible speed > 100mph-125mph	1.3(0.008v)	
Fatigue calculation only		

If the transverse members are not with the direction of train, the dynamic amplification factor is calculated as follow The Value of D.A.F= $1+ \varphi_T$

If the transverse members are not with the direction of train , the dynamic amplification factor is calculated as follow:

$\alpha = 0$ to 25° $[1+\varphi_T]$

$\alpha \geq 25<65^\circ$ $[1+(\varphi_T \cos^2\alpha+\varphi\sin^2\alpha)]$

$\alpha = 65^\circ$ to 90° $[1+\varphi]$

where :

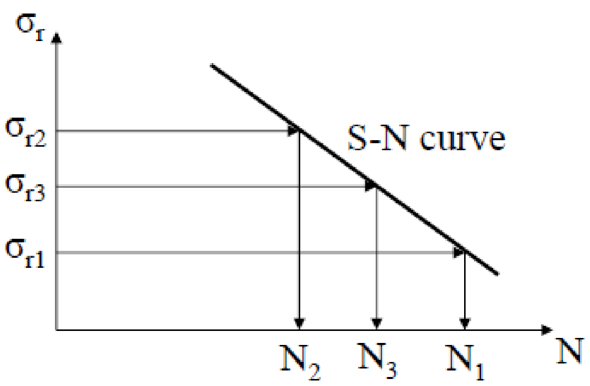
φ_T =dynamic increment from table 4

α = the angle of skew of the transverse member and the truck direction

φ = as designed in the beginning of this section

2.4 Calculation of fatigue damage and rain flow counting using S-N Curve approach

No doubt that trains produce irregular stress histories when crossing bridges and these arbitrary stress histories require an arrangement in an appropriate method to enable counting the stress ranges. The most common method in calculating stress ranges and fatigue damage is called the S-N curve method (for variable amplitude loading), also called as the Palmgren-Miner rule. According to this concept, the fatigue damage at any particular stress range is directly proportional to the number of repeated cycles at this range. The two figures 2A and 2B explains this issue.



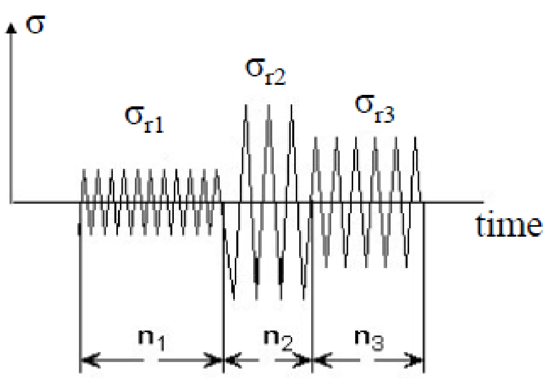


Figure 2 A (S-N) curve

Figure 2B (repeated cycles)

Fatigue damage $= \frac{n_1}{N_1} + \frac{n_2}{N_2} + \frac{n_3}{N3}$

Sum $\frac{n_i}{N_i} = 1$

n_i number of applied cycle at stress range level i

N_i Fatigue life at stress range level i

BS5400 part 10 clause 11.2 prefers the S-N concept and provides suitable tables to classify steel details with respect to their fatigue behaviour.

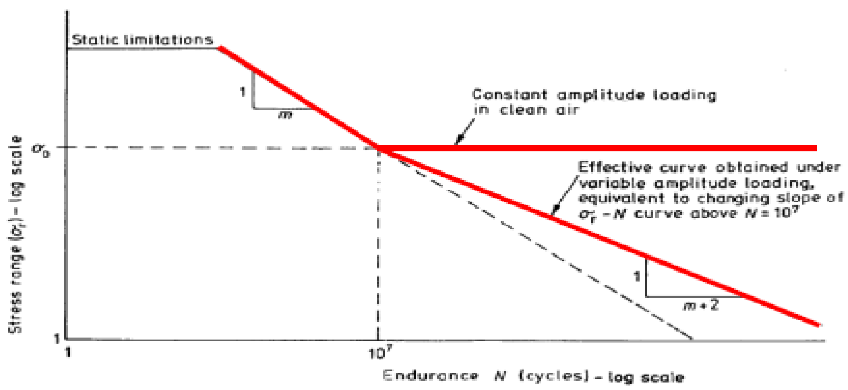


Figure 2C (BS5400 part 10)

$$\frac{n}{N} = \frac{n}{10^7}[\frac{\sigma_r}{\sigma_o}]^m \qquad \text{when } \sigma_r \geq \sigma_o \qquad \text{Equation N1}$$

$$\frac{n}{N} = \frac{n}{10^7}[\frac{\sigma_r}{\sigma_o}]^{m+2} \qquad \text{when } \sigma_r < \sigma_o \qquad \text{Equation N2}$$

σ_r is applied stress range

σ_o is the allowable stress interims of fatigue provided in BS5400 part 10 which is vary due to section classification type.

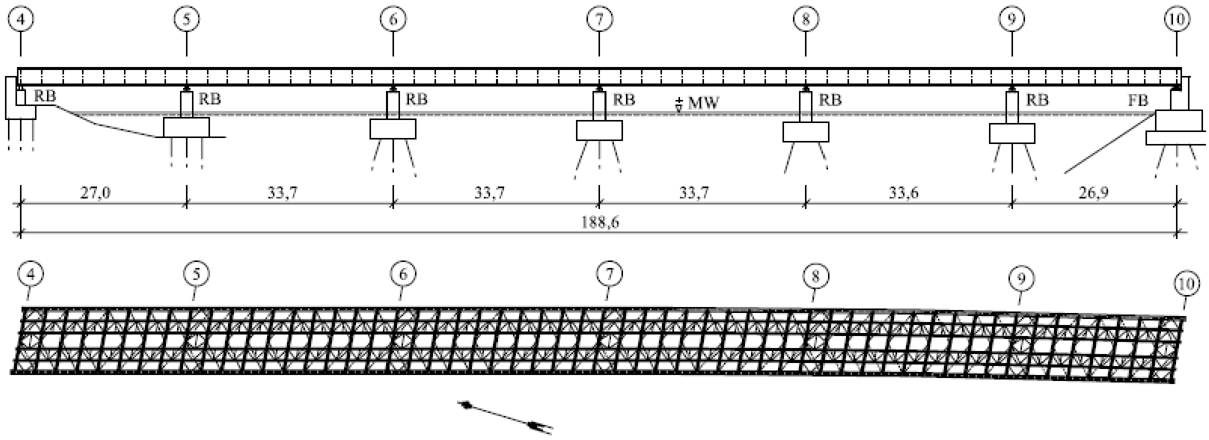
Chapter 3

Case study

3.1 Description of the bridge

Figure (3) Soderstrom bridge view in Stokholm central Sweden (Wallin et al 2011)

The bridge considered in this study is the Soderstrom bridge in central Stockholm (shown in Figure 3). It links the main railway between northern and southern parts of Sweden. It is a six span continuous steel bridge. Almost 520 trains are crossing the bridge including freight and passenger trains (Leander et al. 2009). The total length of the bridge is 190 m and distributed between spans as follows (27.0, 33.7, 33.7, 33.7, 33.6 and 26.9m) from the north to the south of the bridge. Figure 2 shows the spans of the bridge. The bridge has six roller bearings and one fixed on the south position. The bridge has two railway tracks on wooden sleepers which are bolted to the top flange stringer beams (Fig 5) (Wallen et al. 2011). The structure of the bridge consists of stringers which are connected to the cross beams by welds and the cross beams are welded to the main girders as well. Fig 5 shows the details of the welding of three members.



Figure(4) Plan and view of the Soderstrom Bridge over Malaren river.

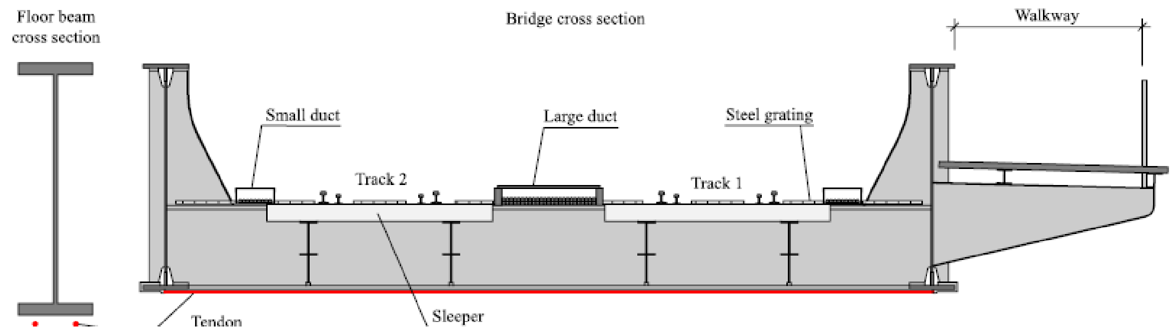


Fig (5) cross section of the Soderstrom bridge (Wallen et al. 2011)

The bridge has a bracing system to resist three actions, wind bracing, brake bracing and horizontal force resistance bracing system. The wind bracings are linked to the midpoint of the floor beams. A brake bracing system was provided near the supports in order to transmit the force generated by acceleration to the main girders. The final bracing system is a zigzag bracing which connects every two parallel stringers and their duty is decreasing the risk of torsion and lateral movements. The wind bracing members are positioned in the bottom of stringer beams, however the zigzag and brake bracing ones link the top flange of the floor beams to the main girder plates. Figure 6 explains the structural components of the bridge between supports 7 and 8.

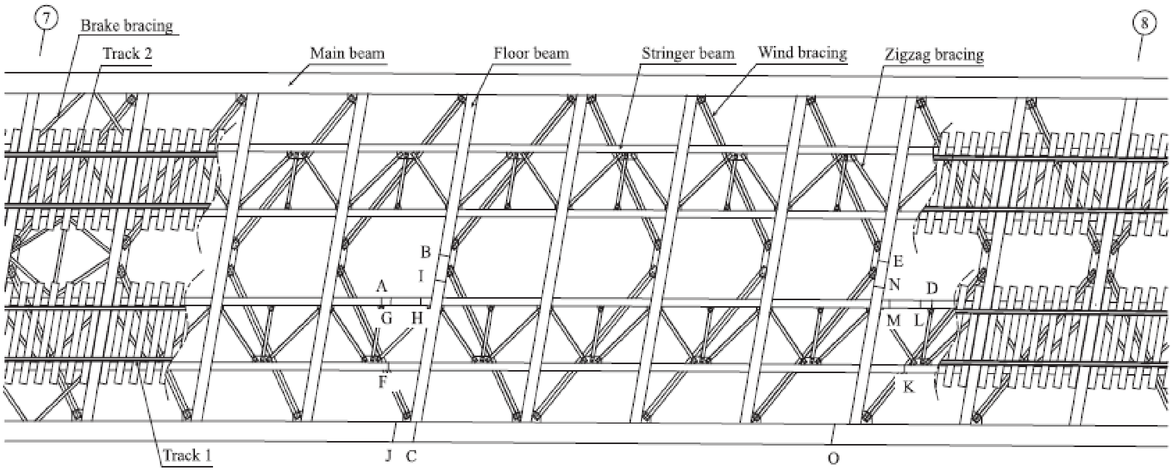
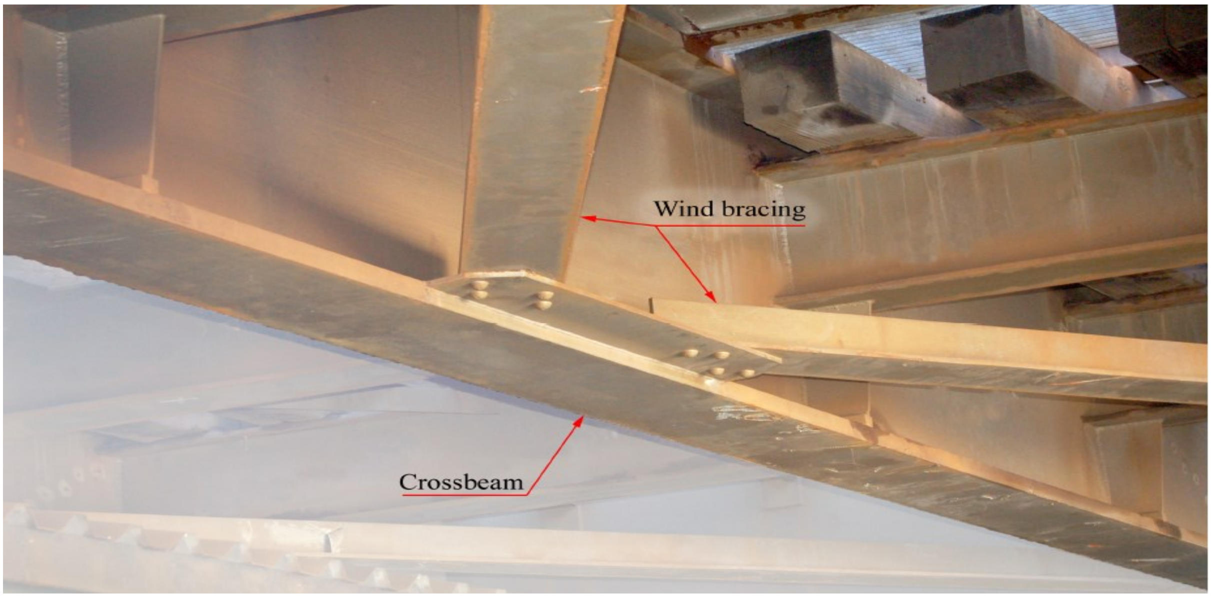


Figure (6) showing the plan of the structural system of Soderstrom bridge wallin et al(2011)

The connection of all members of bracing system are bolted, however the main members are connected by welds. Figure 7 shows the connections of the members in section.



fig(7) cross beam, stringer and wind bracing connections Leander 2010 (23)

The bridge rests on two abutments in the first and last end supports of the bridge whereas the rest of the supports are bearing over two columns in each support, the columns being supported by a concrete slab foundation along the width of the bridge. As mentioned before, the trains crossing railway bridges can be divided into passenger trains, service (empty locomotive) trains and freight trains. According to the Sweden traffic plan in 2008, commuter trains account for almost 90% of all train passages, the other types having only a 5% contribution each. In addition it was shown that the track speed on the bridge was limited to 82km/hr recently. (Wallin et al. 2011).

3.2 Field measurements

3.2.1 Monitoring program

In 2008, a monitoring program has been established between supports seven and eight of the Soderstrom bridge sponsored by the Swedish Rail Administration (Banverket). The first measurements of the program started on 30 July 2008, the data was collected for a period of 43 days (Wallen et al. 2011). All bridge elements (cross beams, stringers and main girder) were provided with 54 strain gauges and five accelerometers. Another two strain gauges were fitted to the rail to examine the interaction between the track and the bridge (Leander et al. 2011). Strain gauges are separated between two regions, mid span region (points A,C,D,E,I) and the region close to the supports (points B,F,G,H,J); the gauges are fitted to the top and bottom flanges of the bridge members. Figures (8A) and (8B) indicate the distribution of the strain gauge in both of these regions.

Figure(8.A) locations of strain gauges in mid span region.

Figure (8.B) strain gauge positions near the support region.

3.2.2 Data acquisition system

A special program was proposed to collect data from field measurements; a ML801 amplifier manufactured from Hettinger Baldwin Messtechnek was used to transfer the data to the laptop by using catman professional software. The data from 62 channels recorded the signals from strain gauges and accelerometers. 400 HZ was used as sampling frequency and before AD-conversion they applied a cut off of 100 HZ as analogue low pass filter. The resolution of the system was 20 bits which has an ability to record around 0.03μm/m (Wallin et al. 2011).

3.2.3 Calibration measurement

The Swedish RC6 locomotive was used to load the bridge having a total weight of 78.0 tonnes and the distance between its axles being 2.7m+5.0m+2.7m (see figure (8C)). The locomotive crossed the bridge with the speeds between 1km/hr to 82km/hr while only the west track was loaded. All measurements have been carried out during night time and there was no other traffic on the bridge during the test Leander et al. (2009).

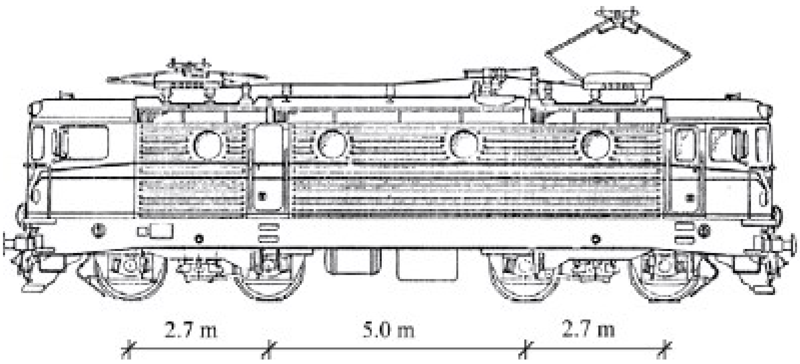


Figure (8c) RC6 Swedish locomotive used for field measurements (Wallin et al. 2011)

The field measurements were recorded at different times with different velocities for different points and members as shown in table (5)

Table (5) time and file names for the recorded data

Nr	Starttid	Lok	Spår (Ö/V)	Riktning (S/N)	Hastighet (km/h)	Filnamn
1	01:53:30	Rc6	V	N	80	080730_499
2	02:00:04	Rc6	V	S	9-10	080730_500
3	02:07:29	Rc6	V	N	82	080730_500
4	02:13:23	Rc6	V	S	10	080730_501
5	02:24:16	Rc6	V	S	70	080730_502
6	02:27:44	Rc6	V	N	70	080730_502
7	02:31:24	Rc6	V	S	70	080730_503
8	02:36:32	Rc6	V	N	1-12	080730_503
9	02:49:20	Rc6	V	S	1	080730_505
10	03:13:05	Rc6	V	S	1	080730_507
11	03:30:45	Rc6	V	N	51	080730_508
12	03:40:03	Rc6	V	S	1	080730_509
13	04:00:39	Rc6	V	N	52	080730_511

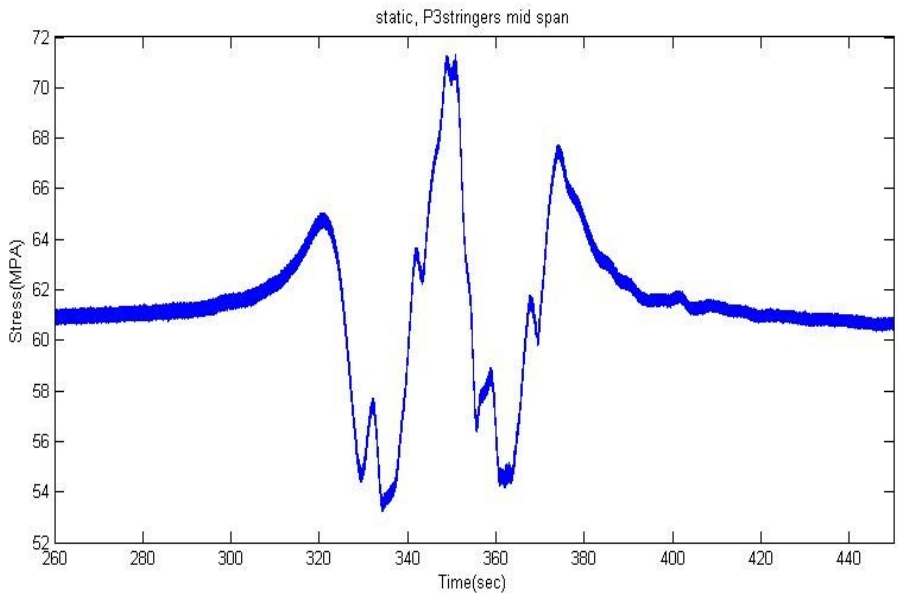
3.3 Plotting stress history from the data for different velocities and members

The data file shown in table 5 are mat lab files, each file provides millions of data recorded for a particular point. However, there are some errors in reading some of the files , hence the corrected files have chosen as a resource data in this dissertation. The data with velocity (1m/h) are chosen as a static data, and the data with velocities (10m/hr, 51mile/hour, 52m/hr, 82m/hr) have plotted by using Matlab software in order to obtain the maximum and minimum stress points. figures (9) to (160) illustrate this issue.

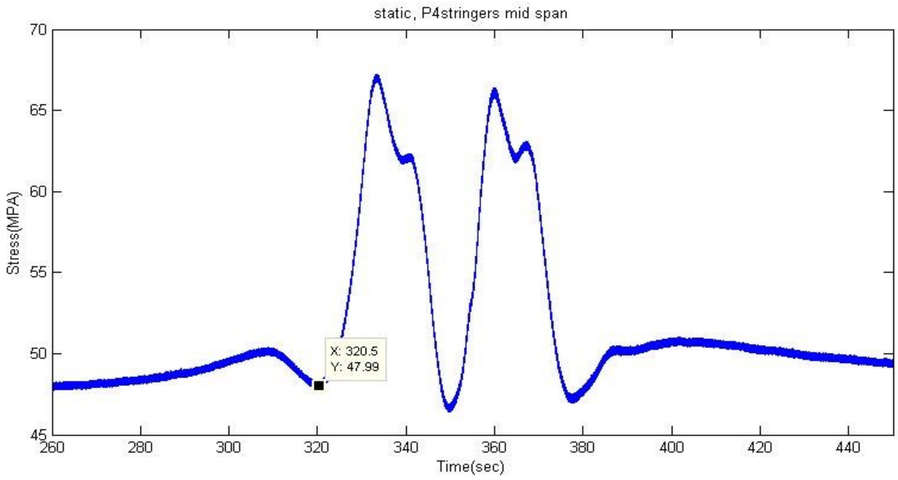
3.3.1 Graphs for 1km/hr (static)

3.3.1.1 stringers

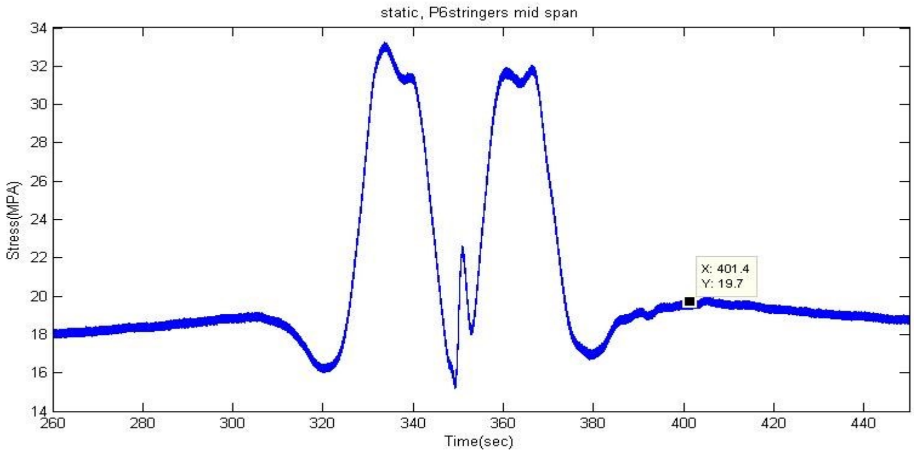
A- mid span points:



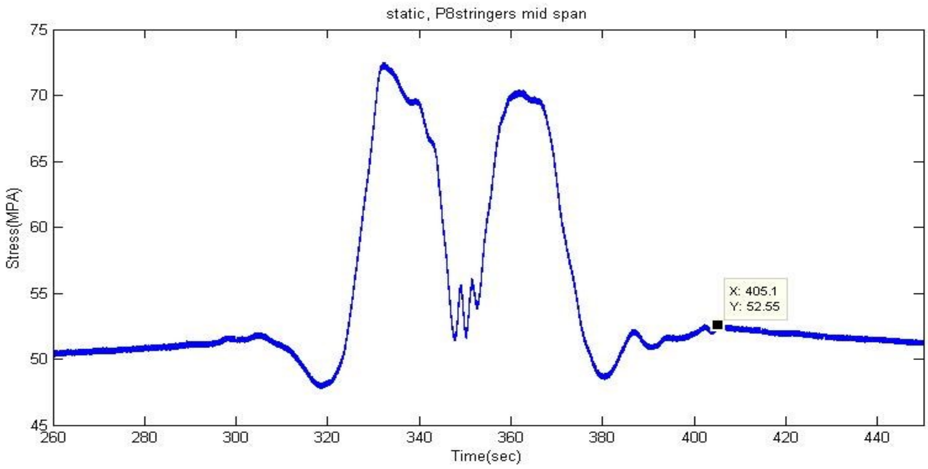
Figure(9) static stress history at point 3



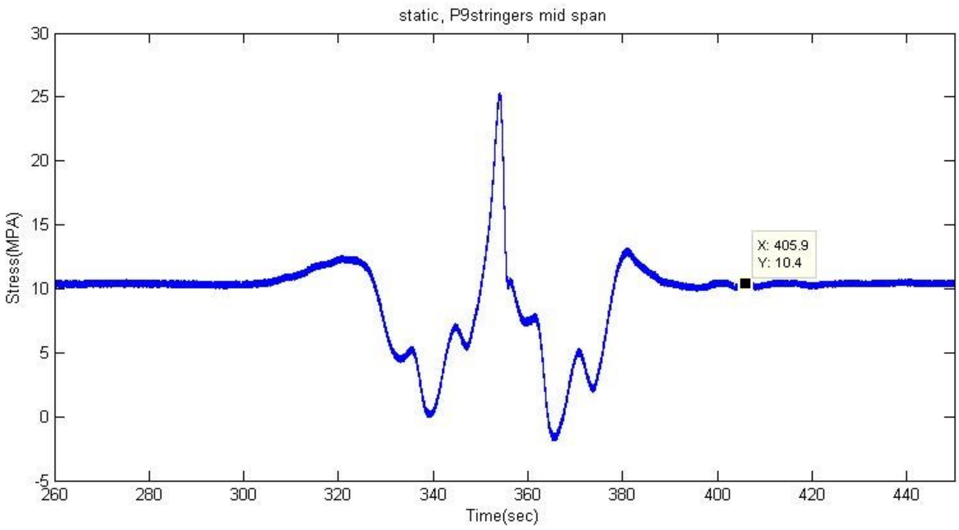
Figure(10) static stress curve for point(4) (midspan)



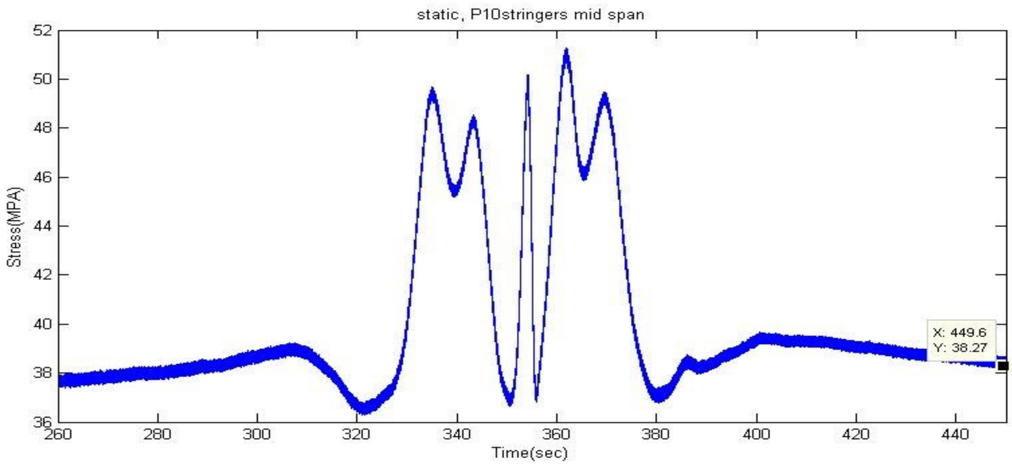
Figure(11) static stress history for point 6



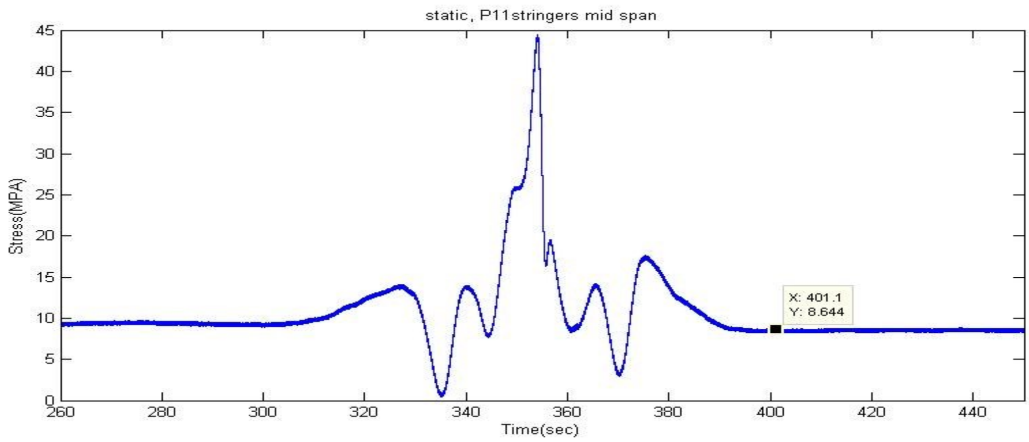
Figure(12)static stress curve for point (8)



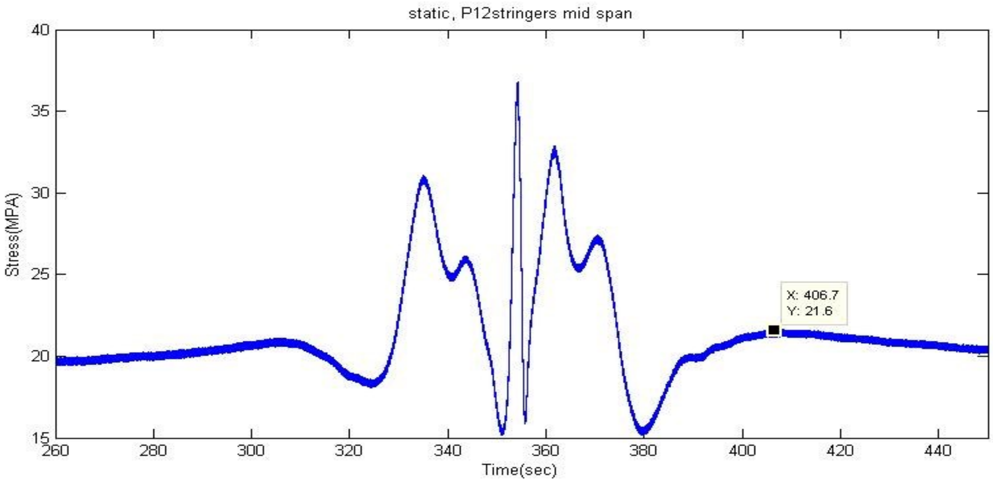
Figure(13)static stress history at point 9



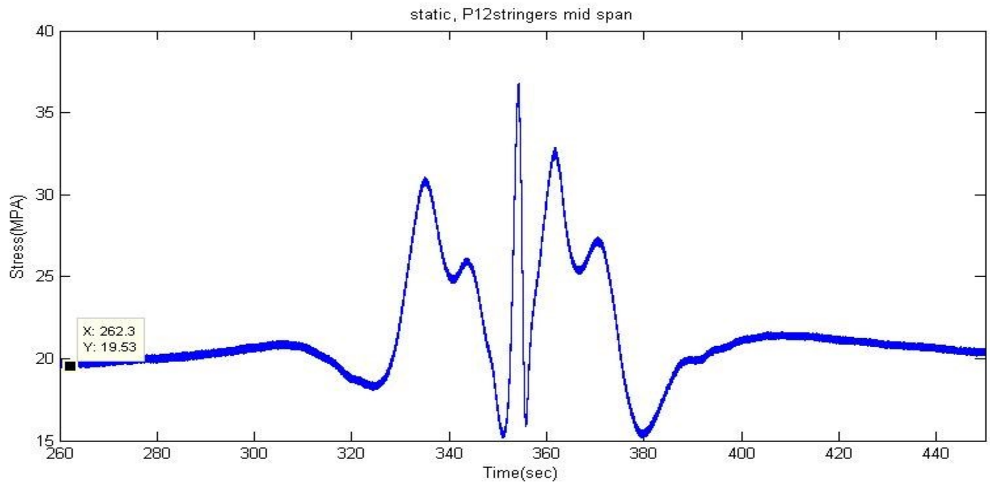
Figure(14) static stress history at point 10



Figure(15) static stress history at point 11

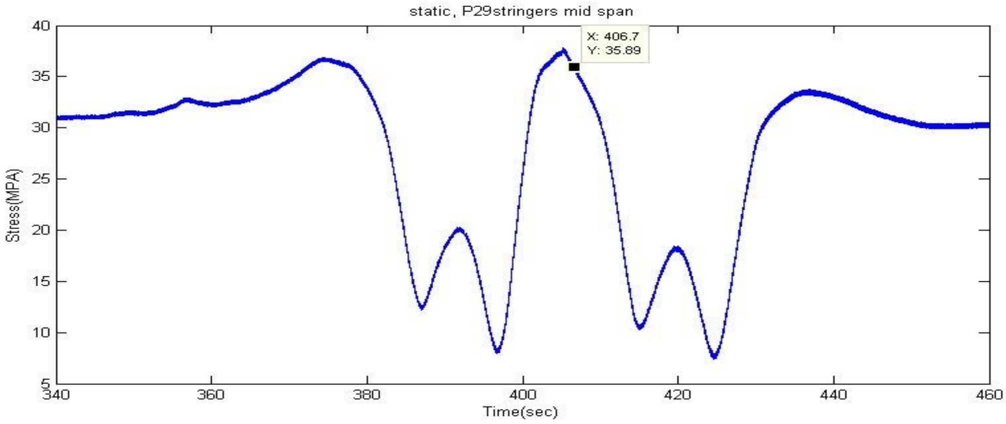


Figure(16) static stress history at point 12

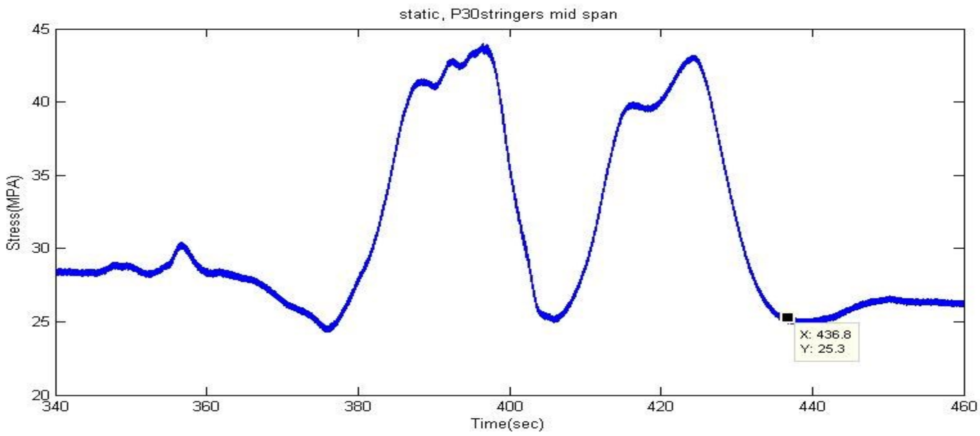


Figure(17) static stress history at point 13

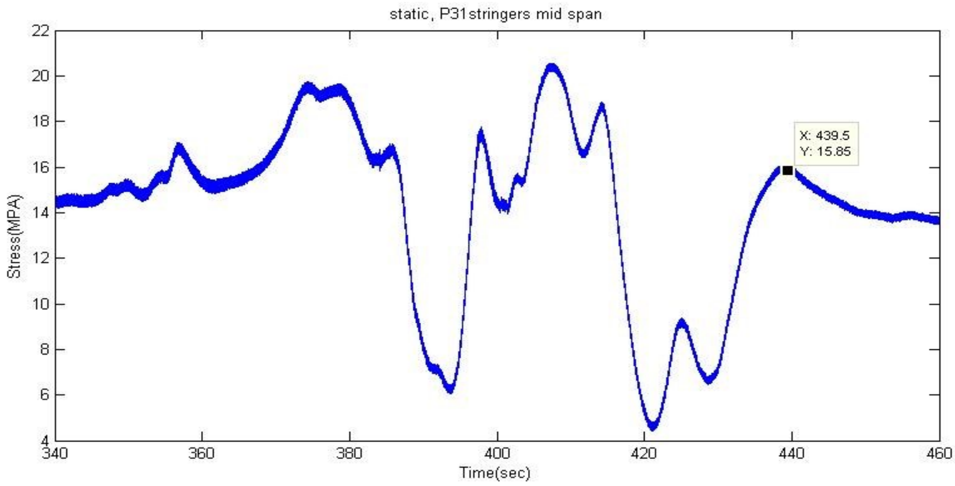
B-support points:



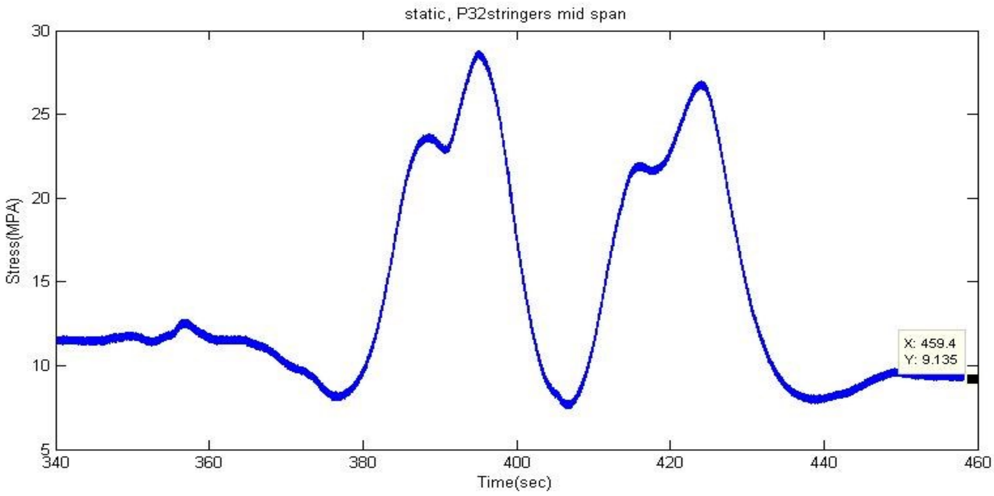
Figure(18) static stress history at point 29



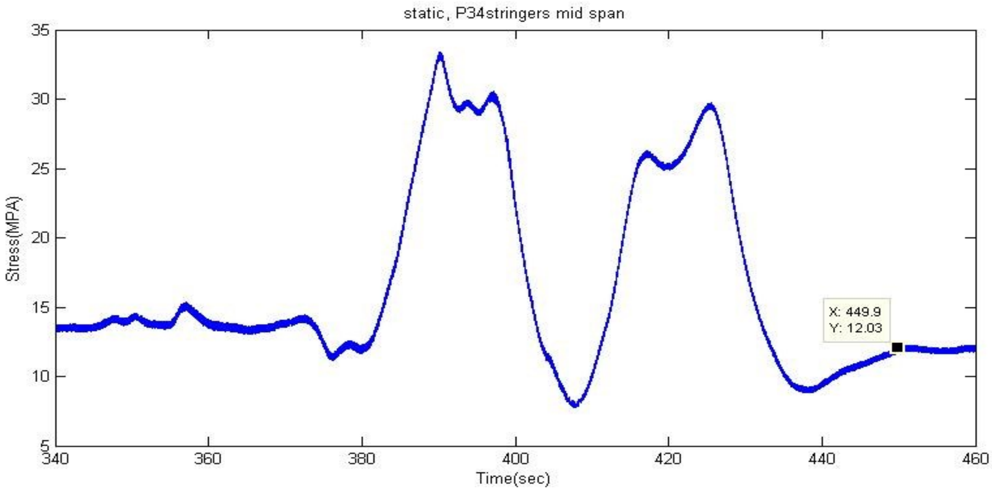
Figure(19) static stress history at point 30



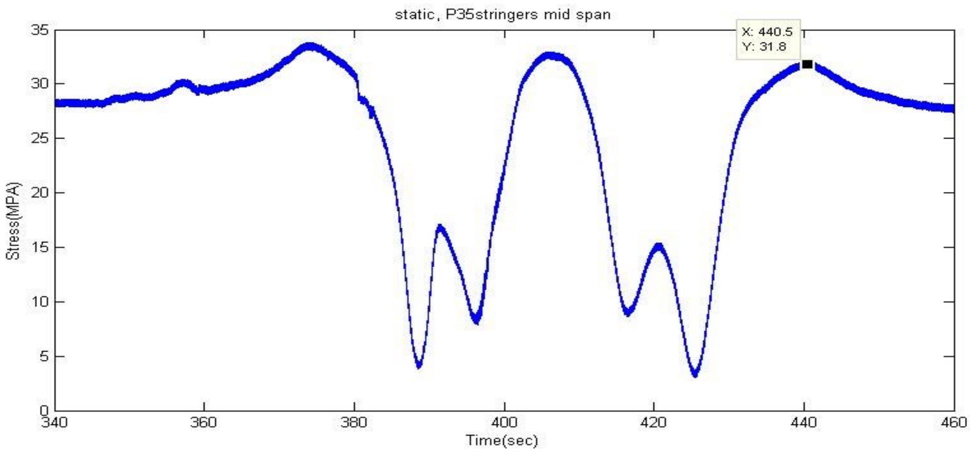
Figure(20) static stress history at point 31



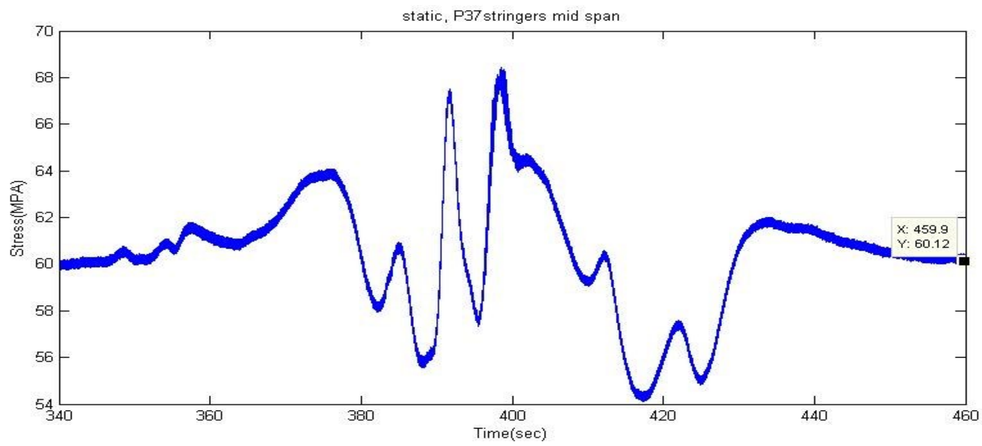
Figure(21) static stress history at point 32



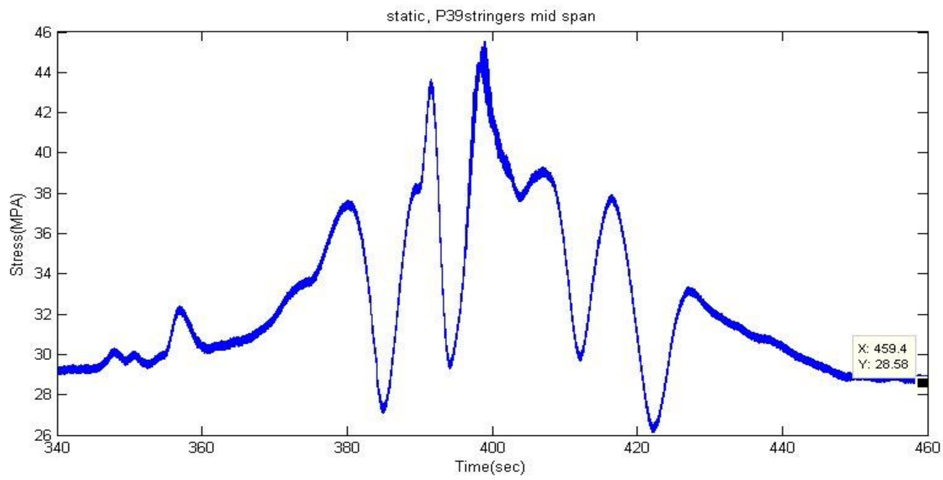
Figure(22) static stress history at point 34



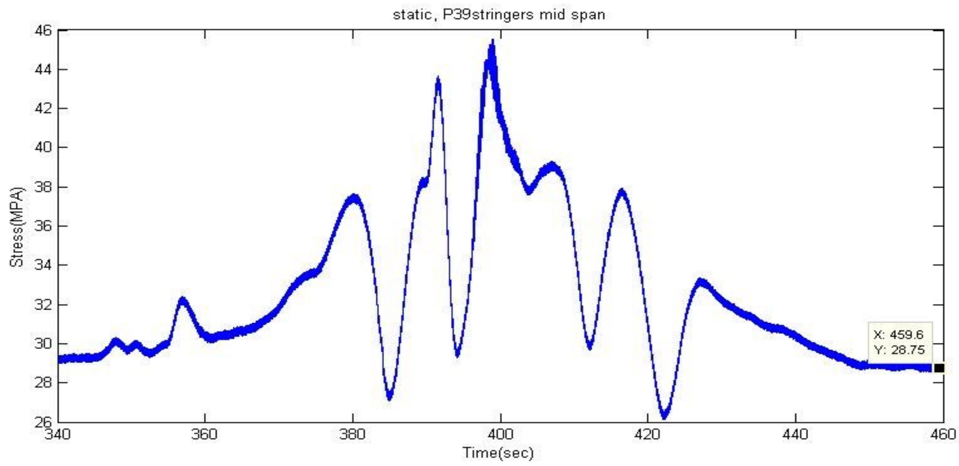
Figure(23) static stress history at point 35



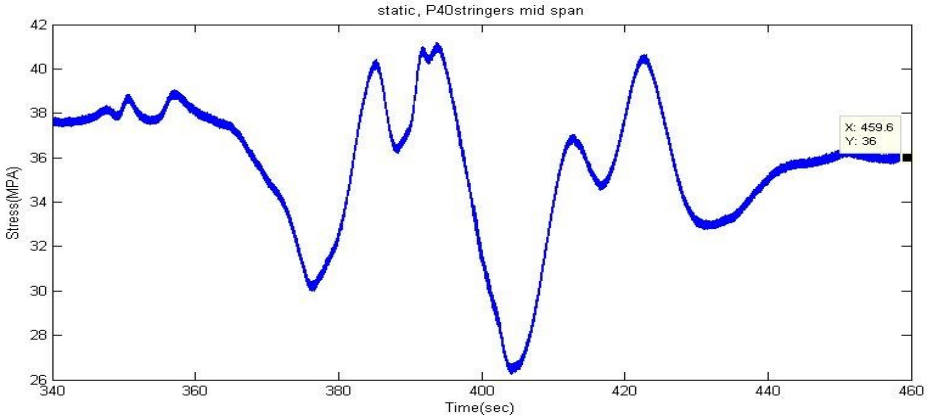
Figure(24) static stress history at point 37



Figure(25) static stress history at point 38



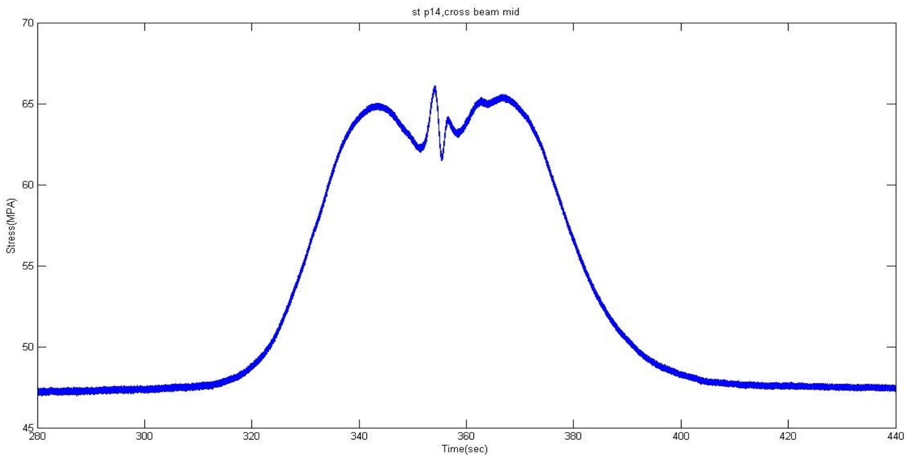
Figure(26) static stress history at point 39



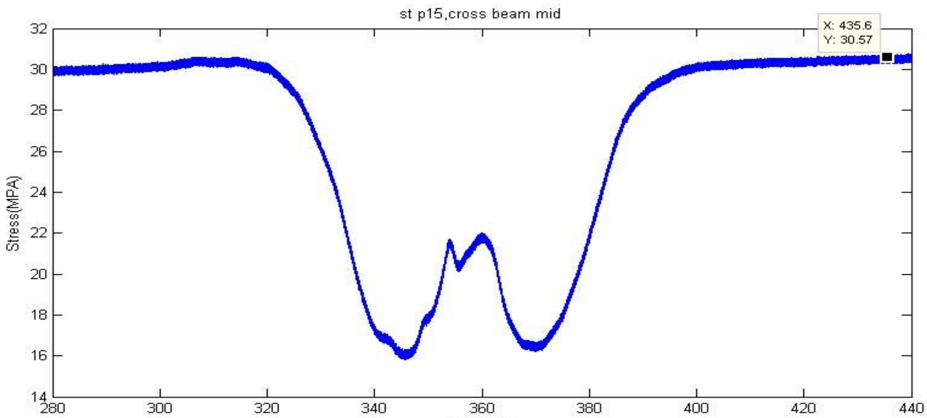
Figure(27) static stress history at point 40

3.3.1.2 Cross beams

A- mid span region

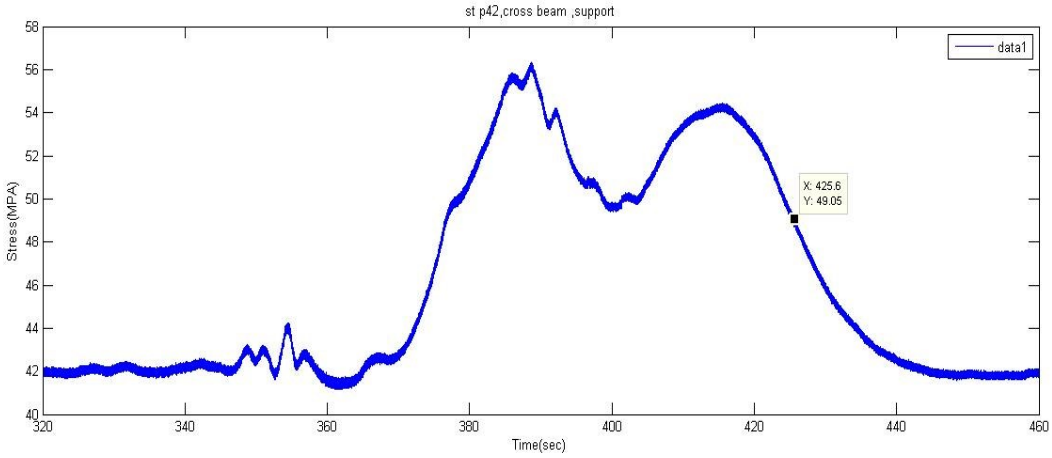


Figure(28) static stress history at point 14

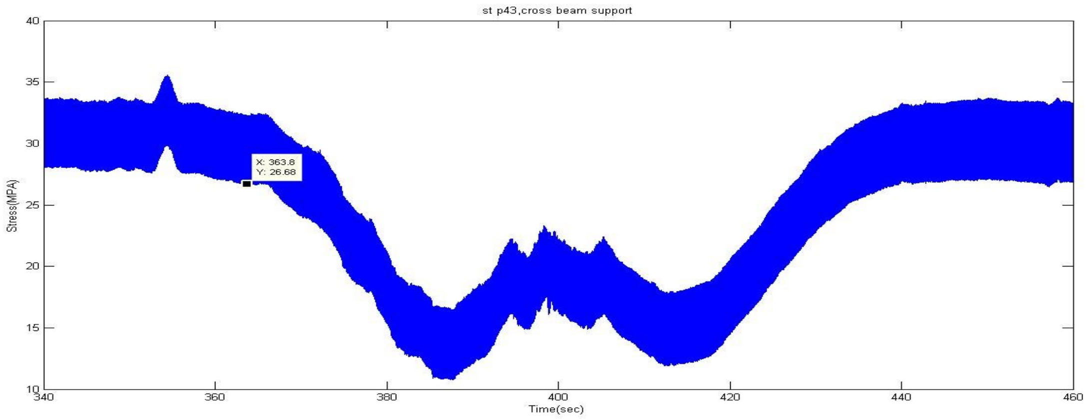


Figure(29) static stress history at point 15

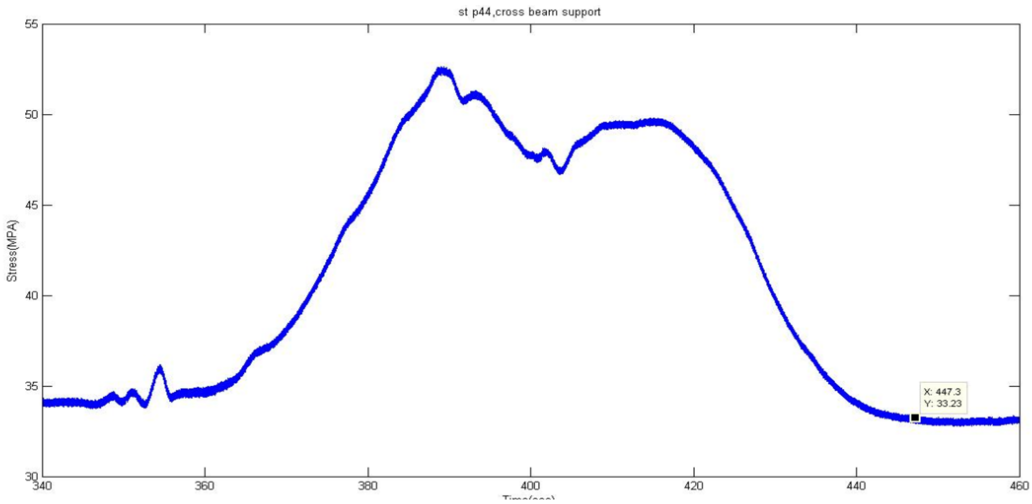
B- support region



Figure(30) static stress history at point 42



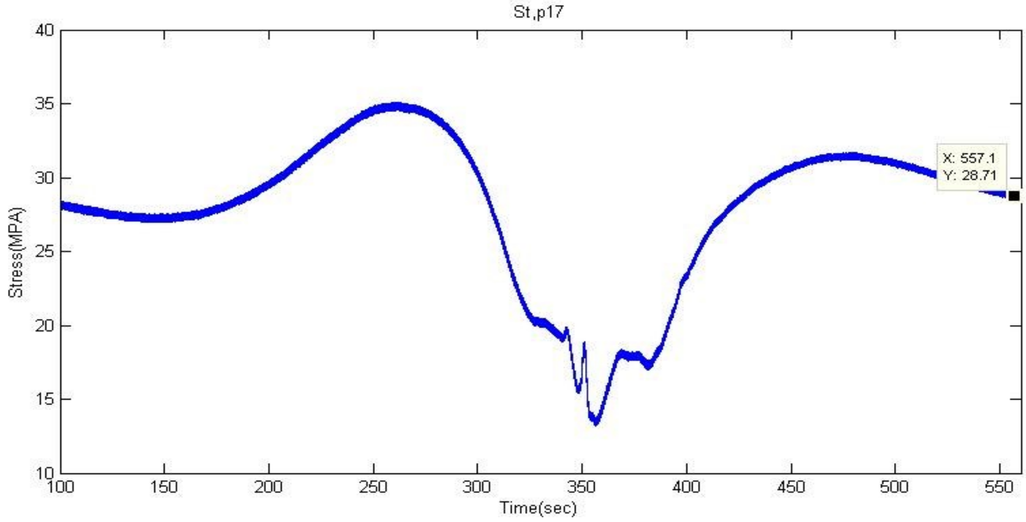
Figure(31) static stress history at point 43



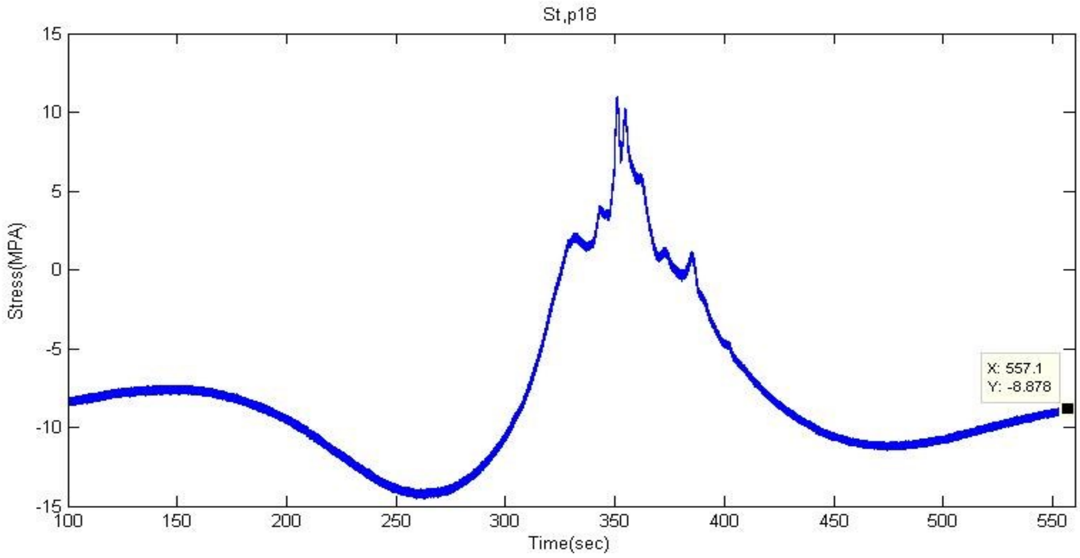
Figure(32) static stress history at point44

3.3.1.3 Main girders

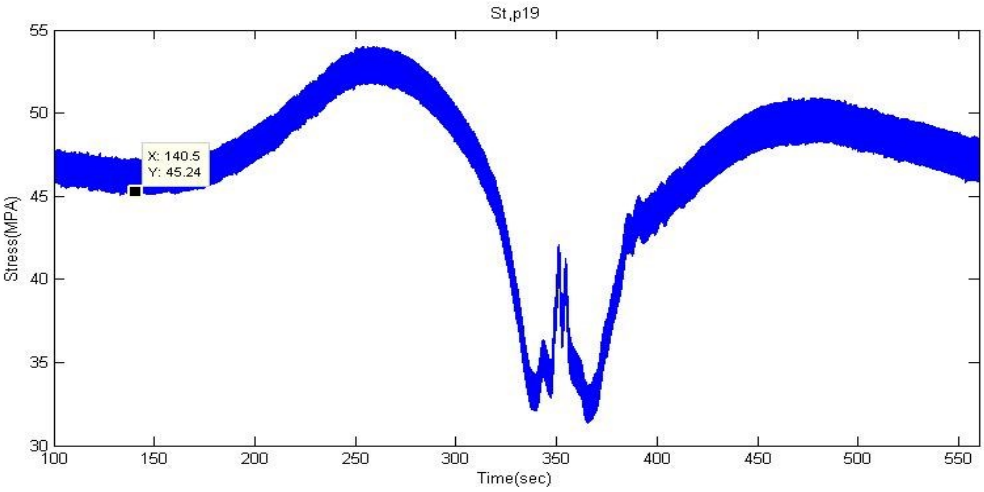
A- Mid pan



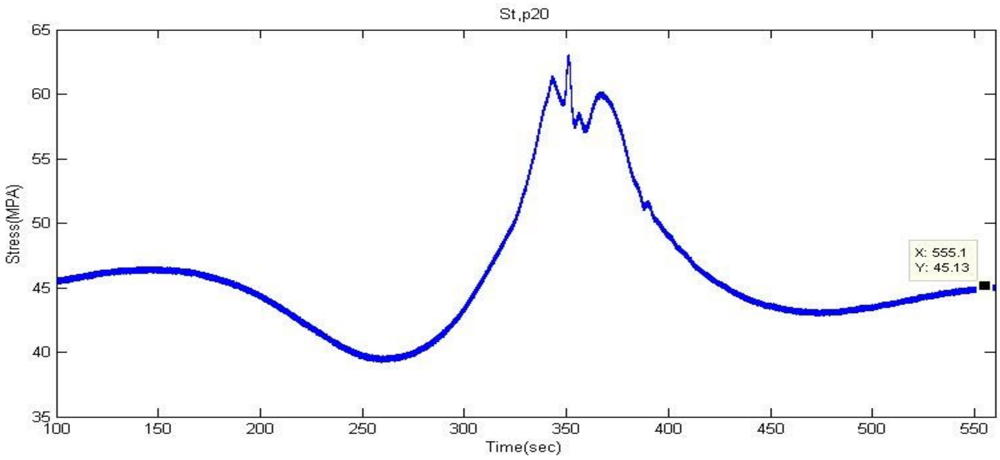
Figure(33) static stress history at point17



Figure(34) static stress history at point18

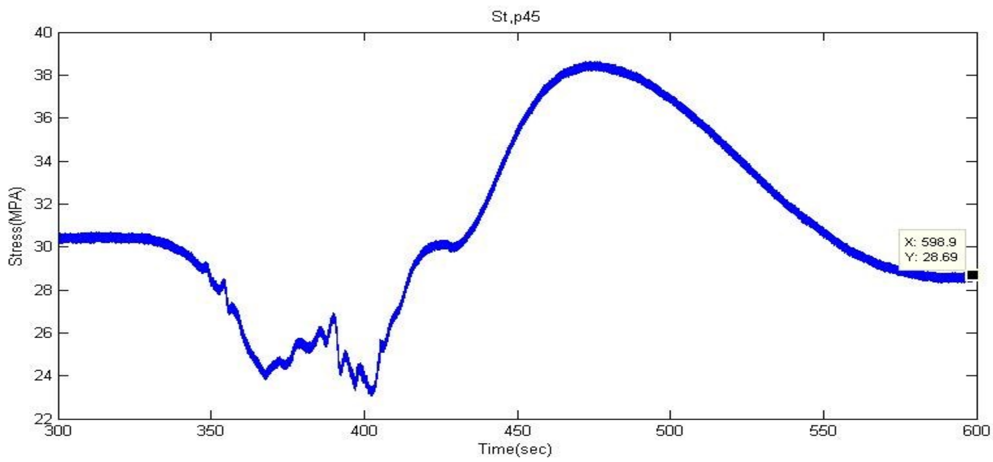


Figure(35) static stress history at point19

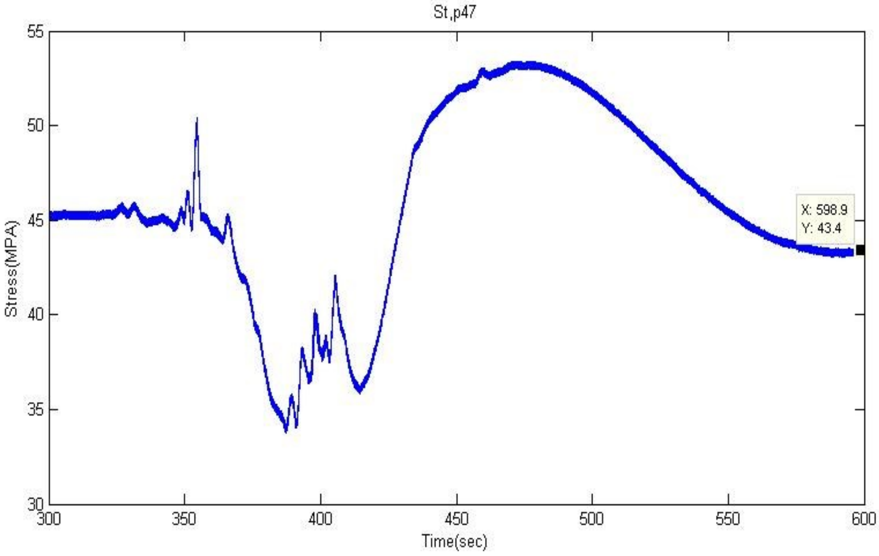


Figure(36) static stress history at point20

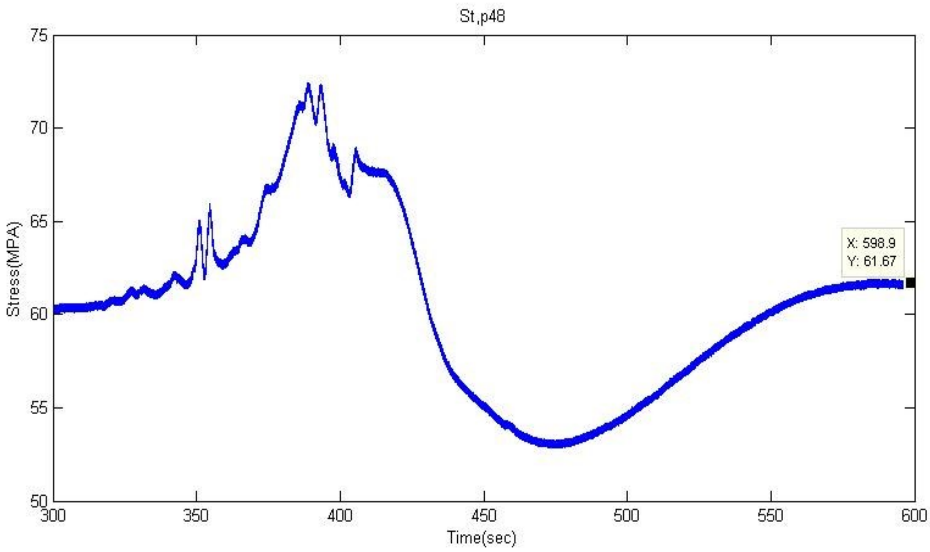
B-Support region



Figure(37) static stress history at point45



Figure(38) static stress history at point47

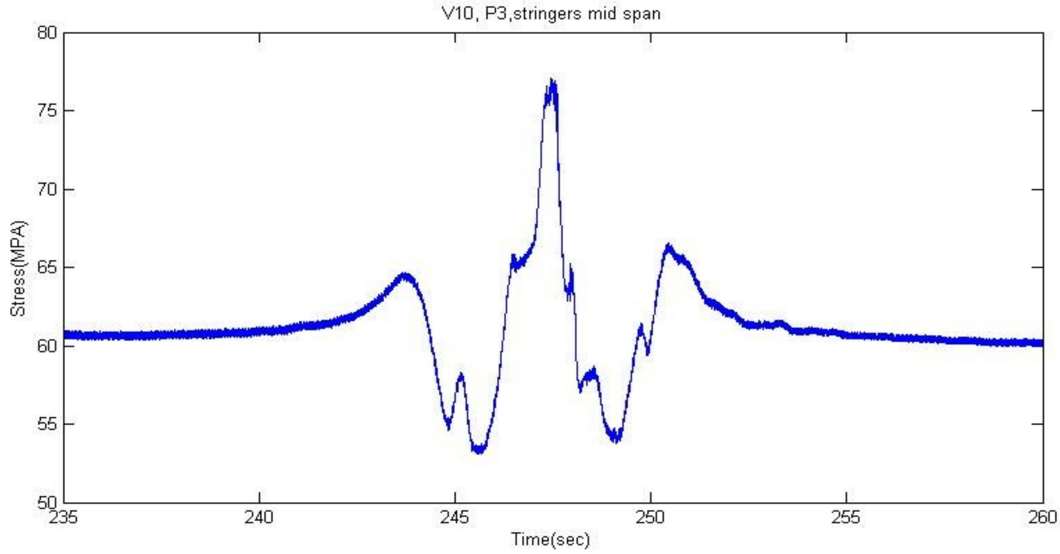


Figure(39) static stress history at point48

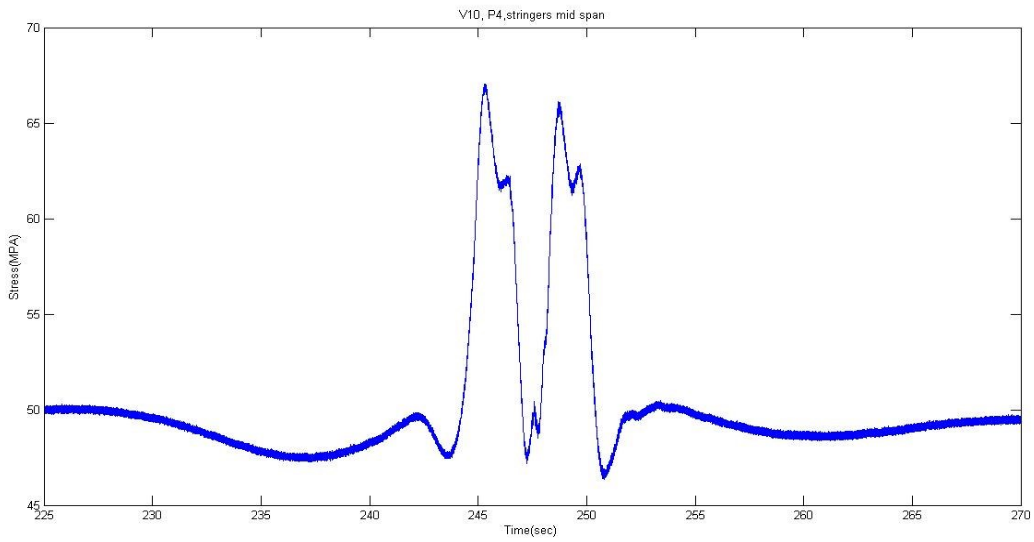
3.3.2 Graphs for velocity (10km/hr)

3.3.2.1 stringers

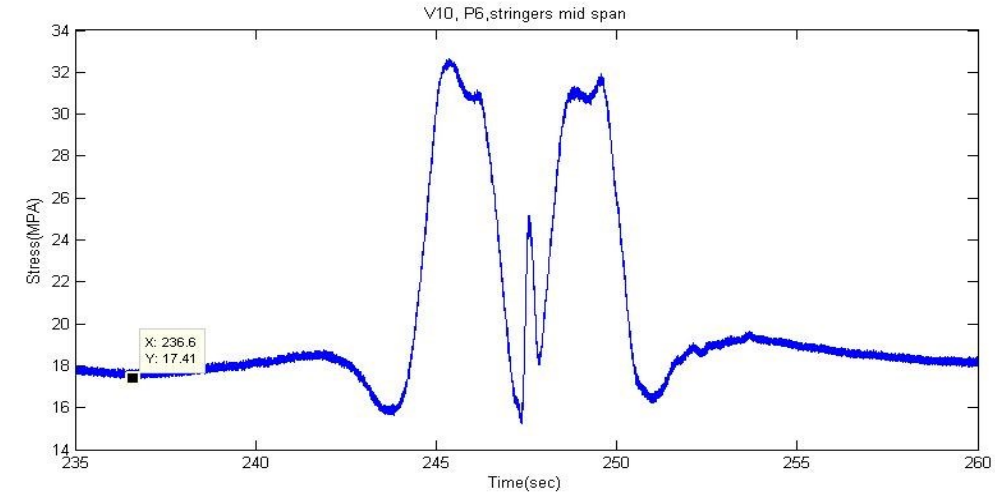
A- mid-span region



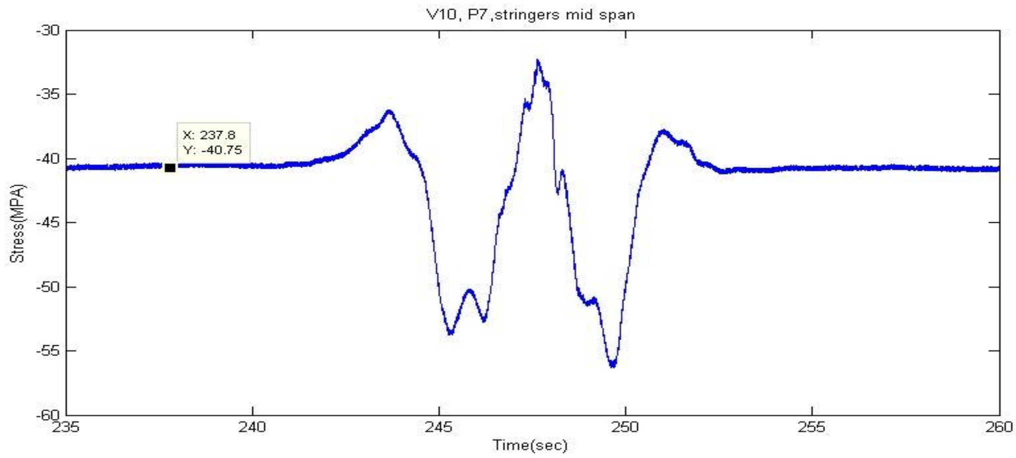
Figure(40) stress history at point3(10km/hr)



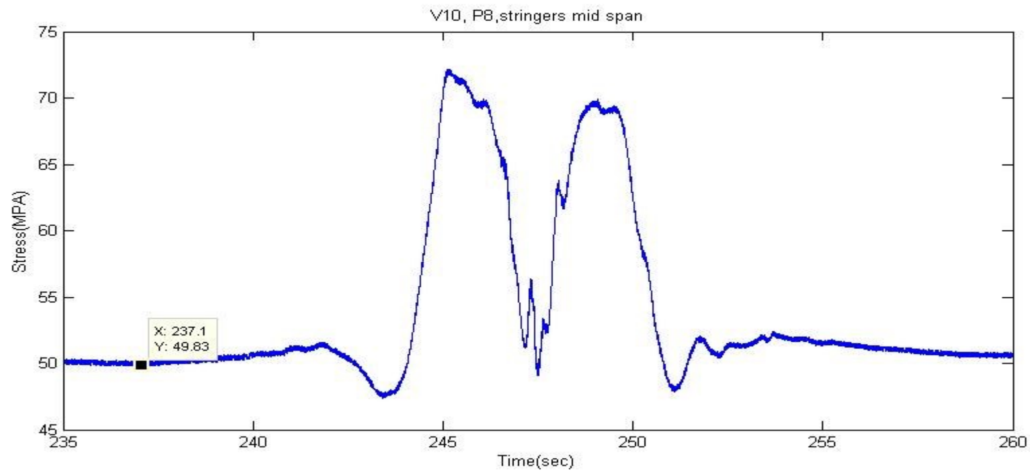
FIGURE(41) stress history at point4(10km/hr)



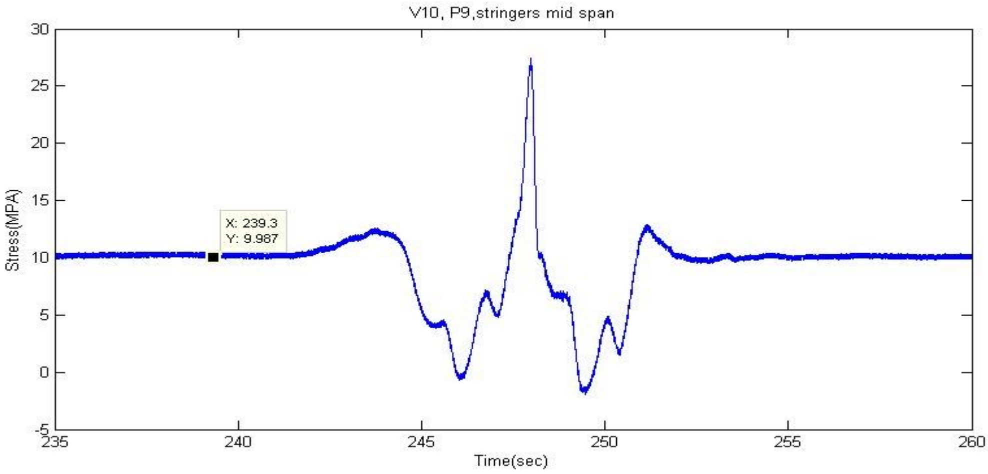
Figure(42) stress history at point 6(10km/hr)



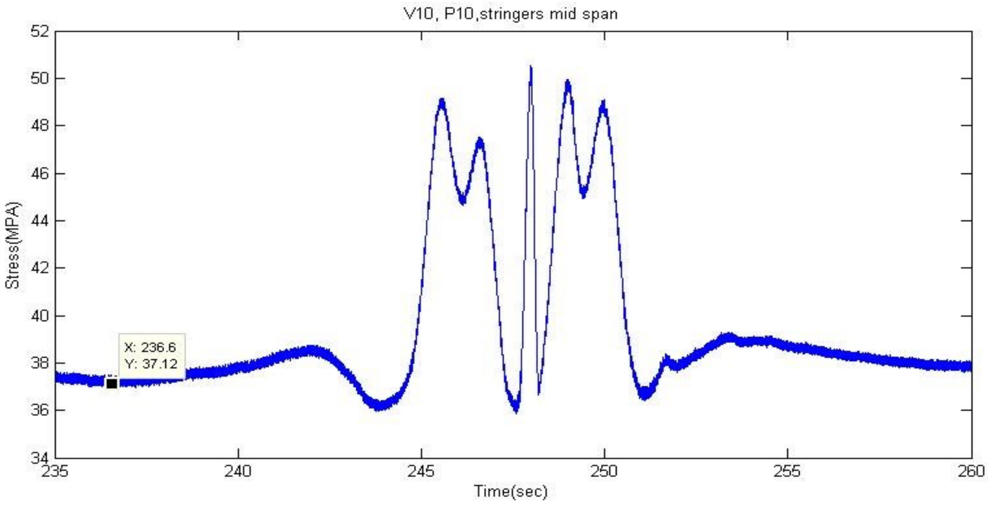
Figure(43) stress history at point 7(10km/hr)



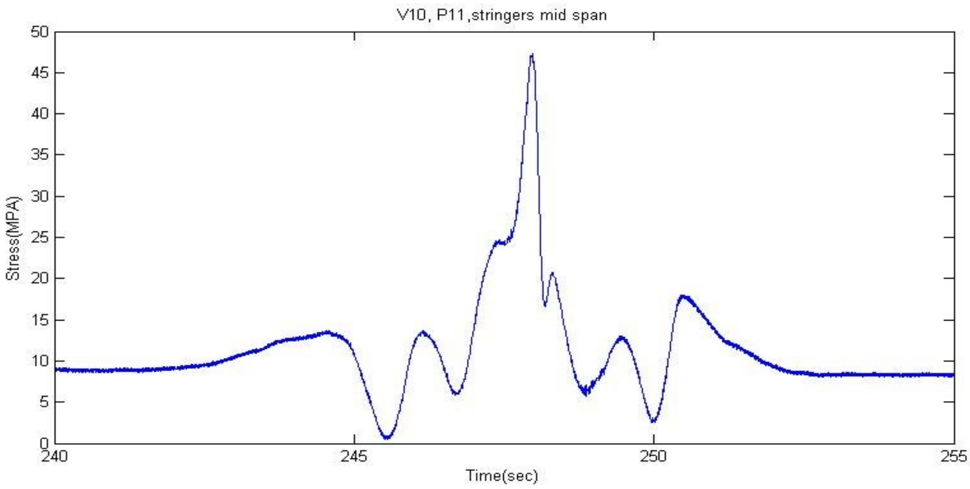
Figure(44) stress history at point 8(10m/hr)



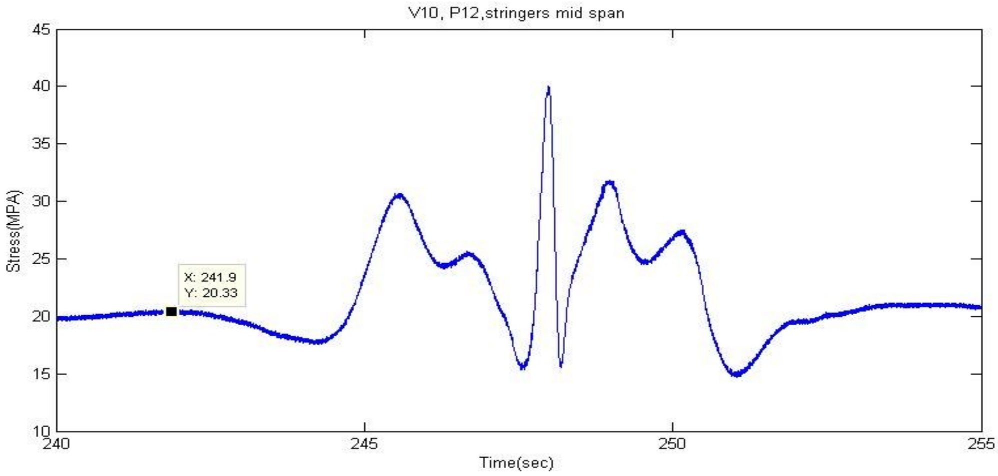
Figure(45) stress history at point 9(10km/hr)



Figure(46) stress history at point 10(10km/hr)

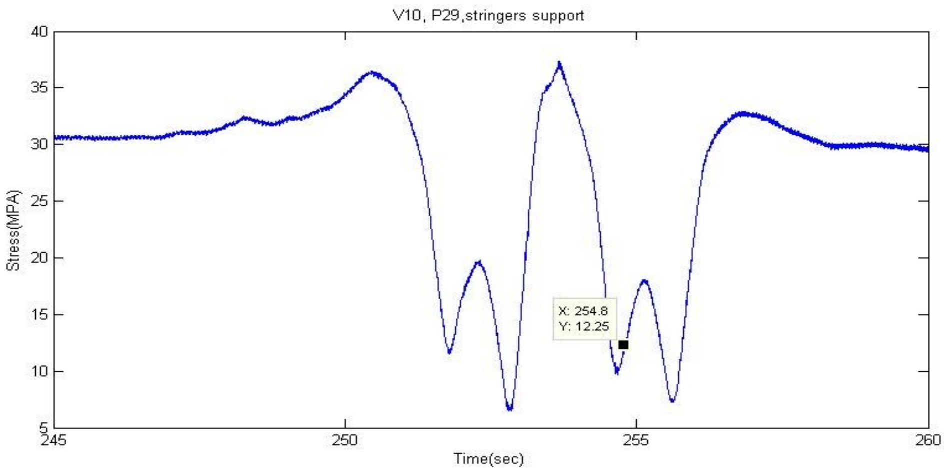


Figure(47) stress history at point 11(10km/hr)

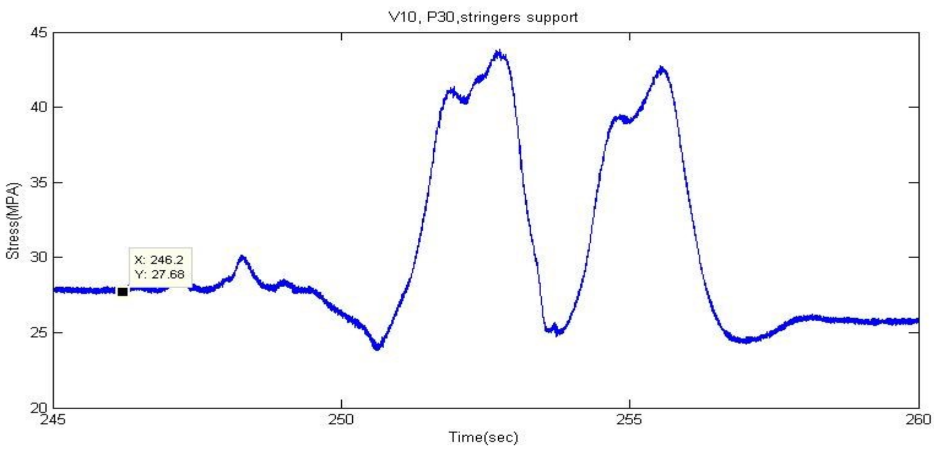


Figure(48) stress history at point 12(10km/hr)

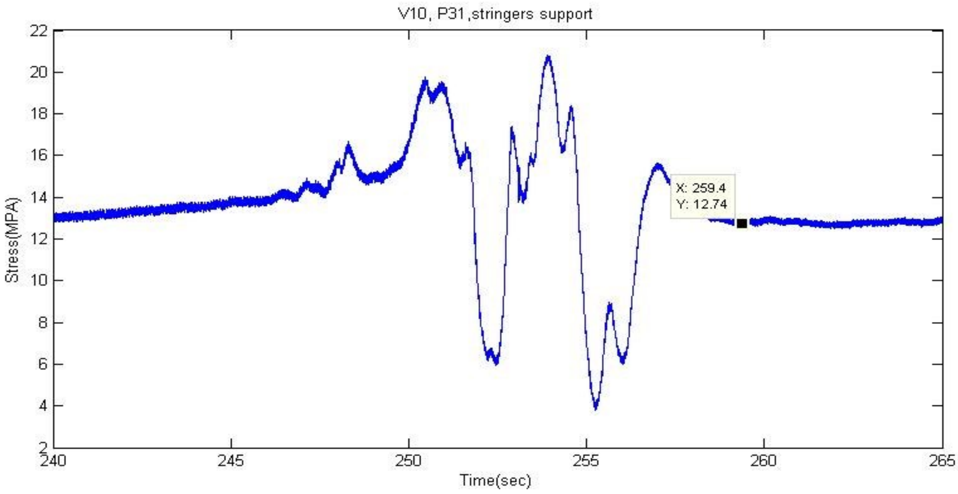
B –support region



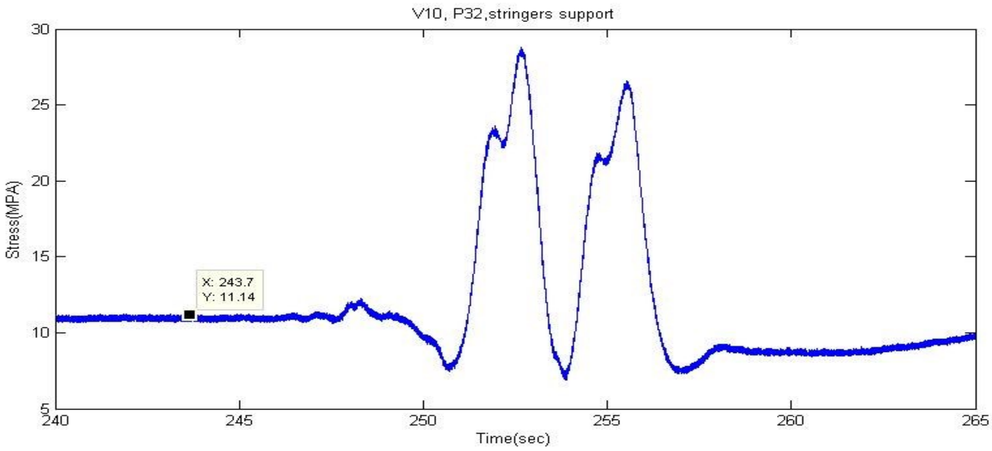
Figure(49) stress history at point 29(10km/hr)



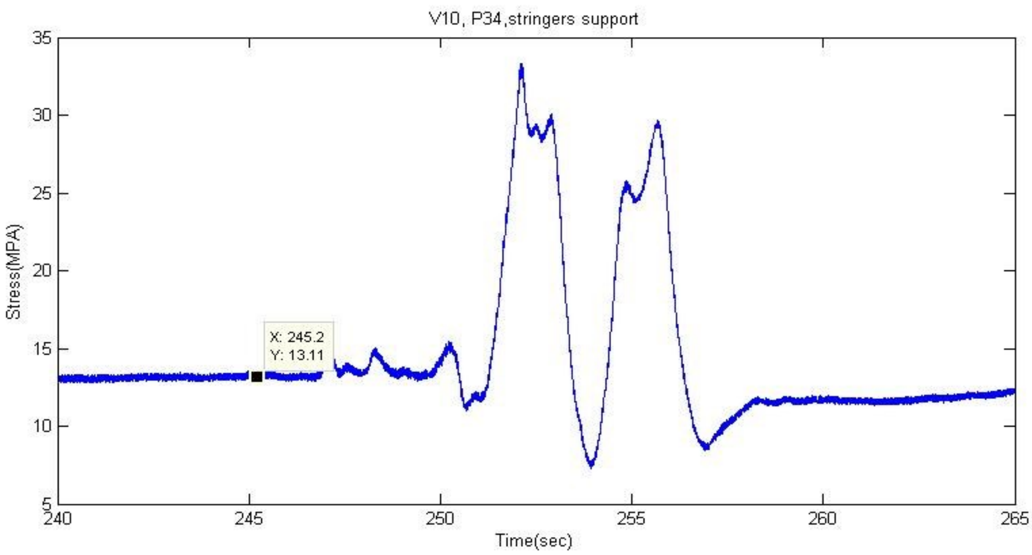
Figure(50) stress history at point 30(10km/hr)



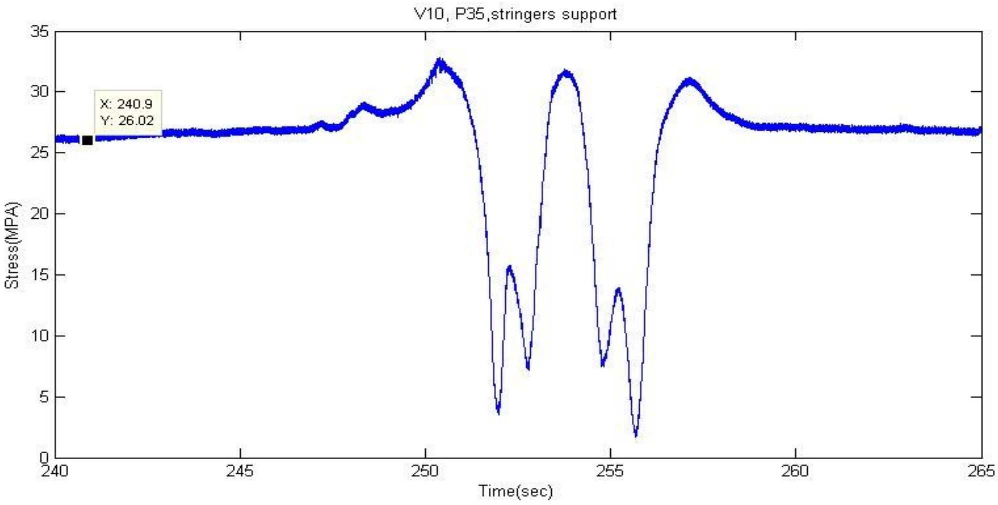
Figure(51) stress history at point 31(10km/hr)



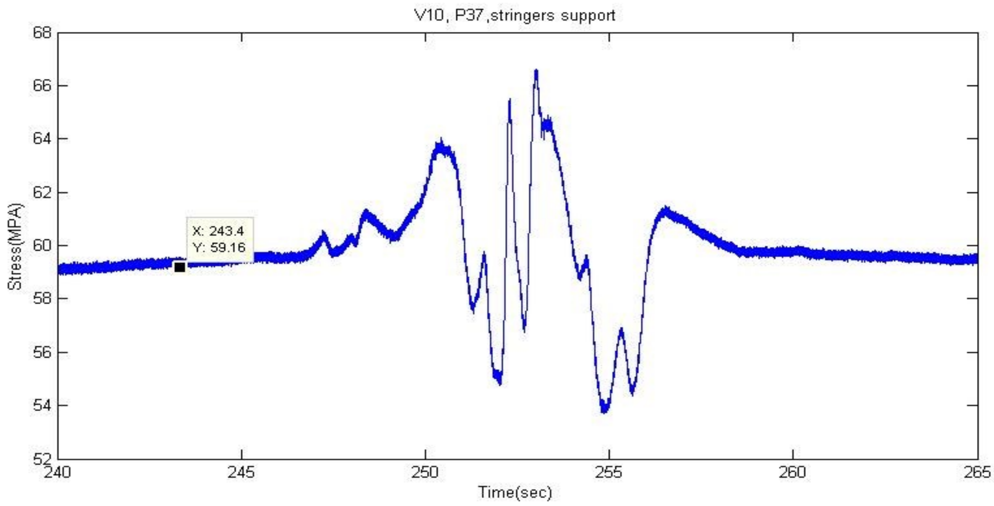
Figure(52) stress history at point 32(10km/hr)



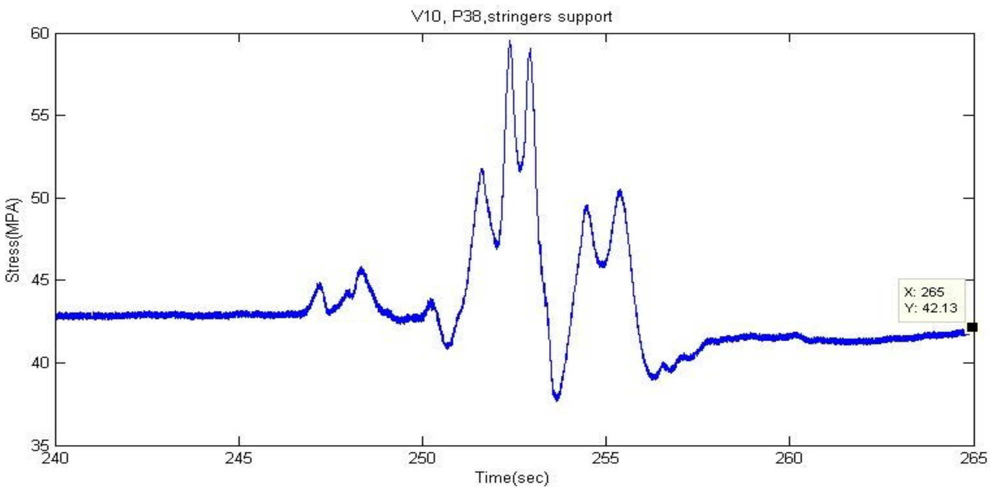
Figure(53) stress history at point 34(10km/hr)



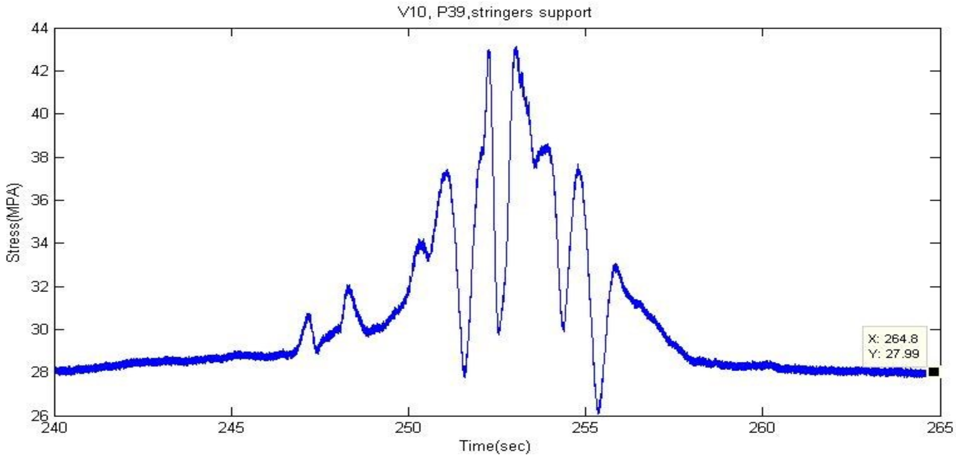
Figure(54) stress history at point 35(10km/hr)



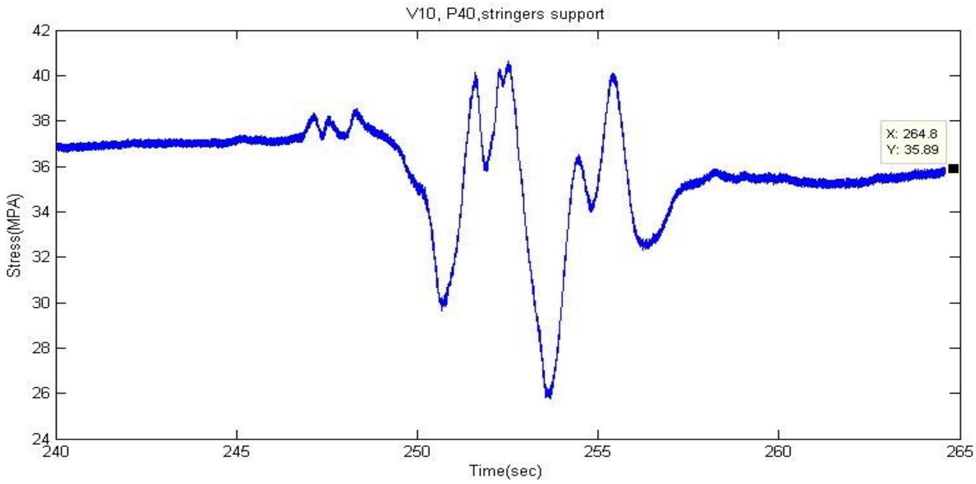
Figure(55) stress history at point 37(10km/hr)



Figure(56) stress history at point 38(10m/hr)



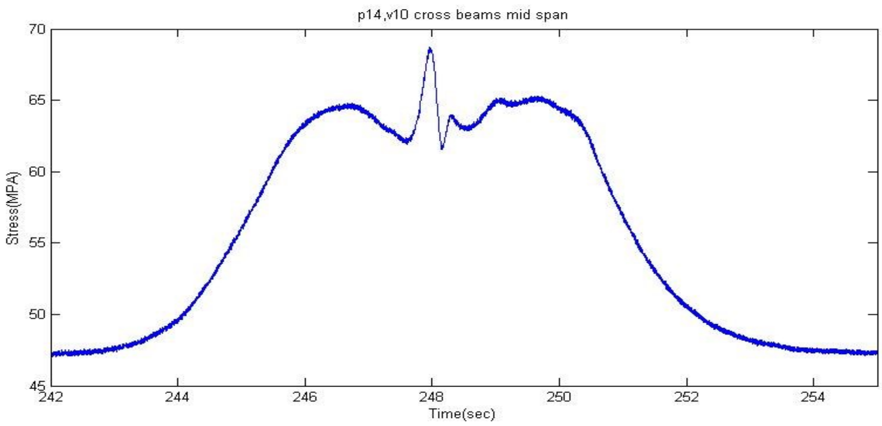
Figure(57) stress history at point 39(10km/hr)



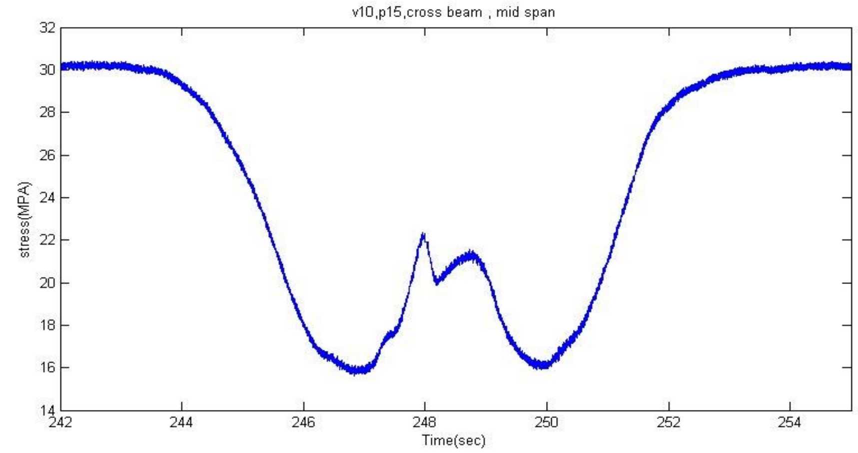
Figure(58) stress history at point 40(10km/hr)

3.3.2.2 Cross beams

A-Mid span

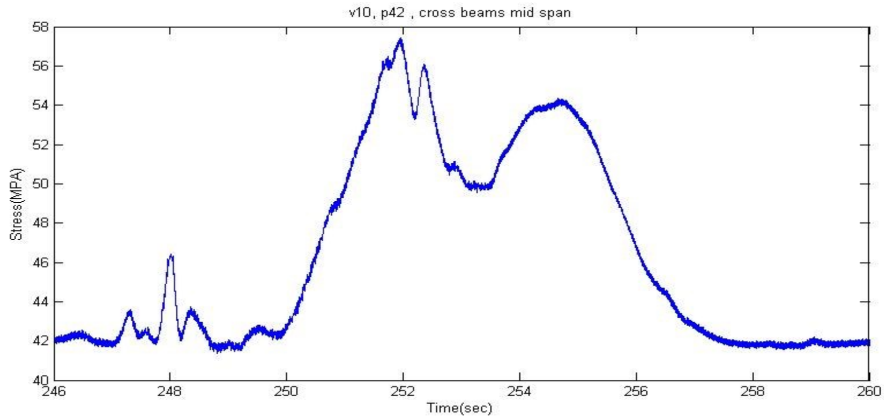


Figure(59) stress history at point 10(10km/hr)

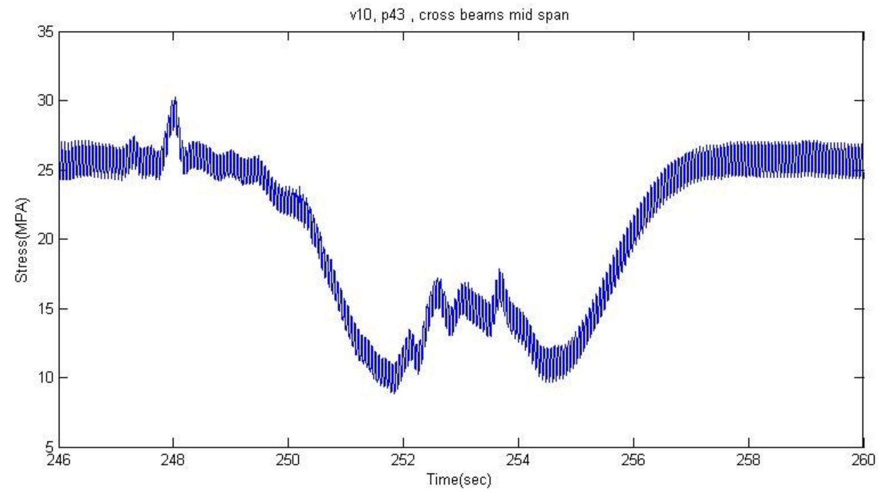


Figure(60) stress history at point 15(10km/hr)

B-support region



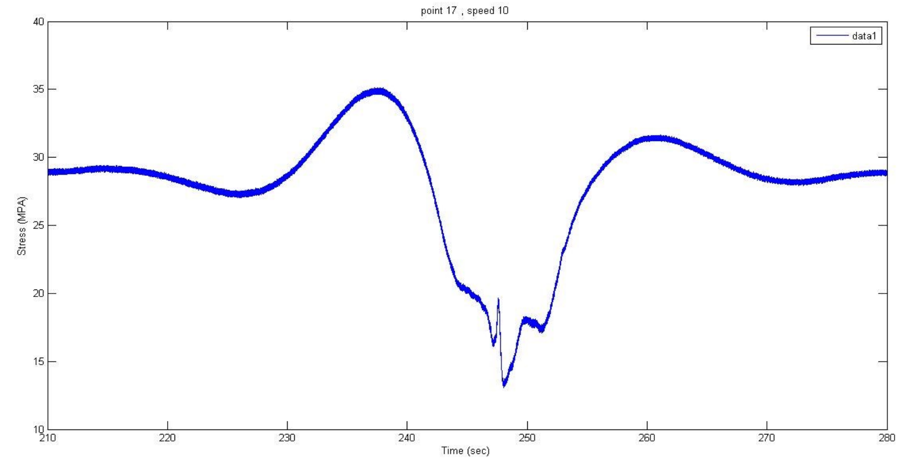
Figure(61) stress history at point 42(10km/hr)



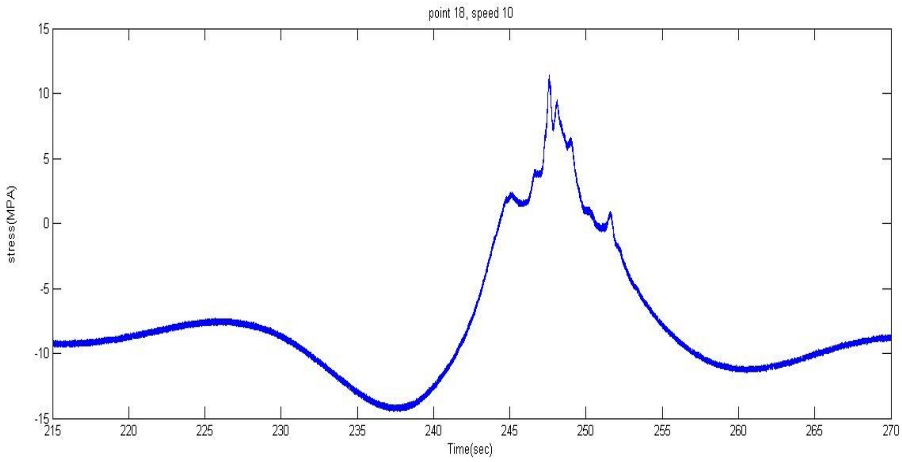
Figure(62) stress history at point 43(10km/hr)

3.3.2.3 Main girders

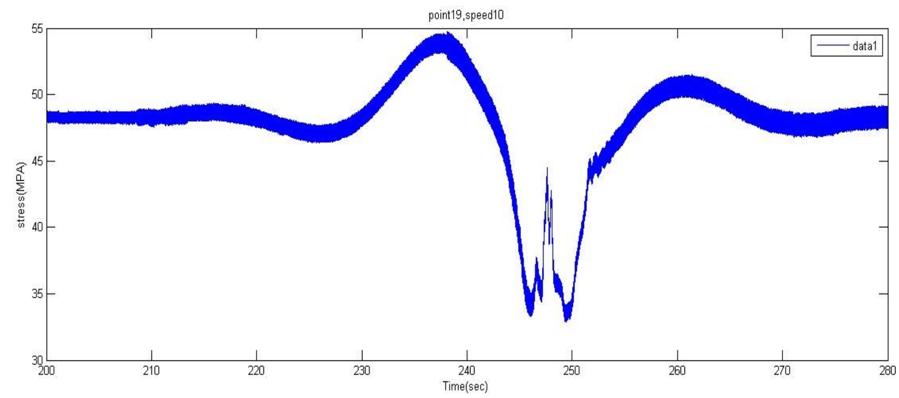
A-Mid span



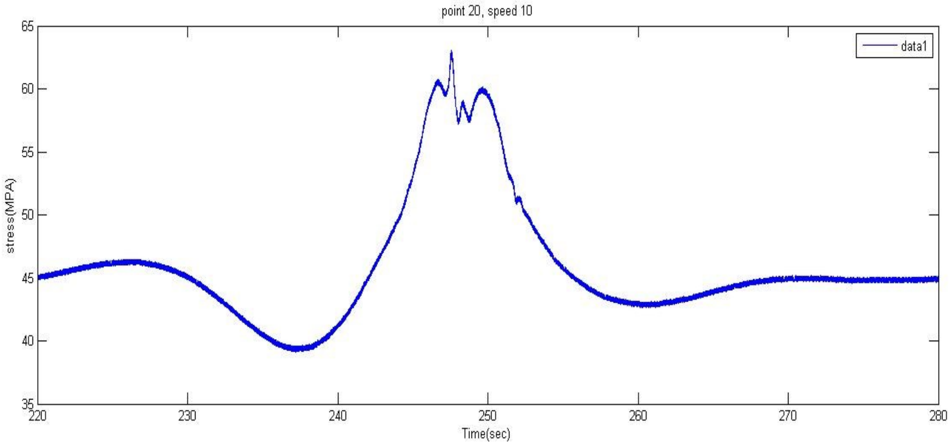
Figure(63) stress history at point 17(10km/hr)



Figure(64) stress history at point 18(10km/hr)

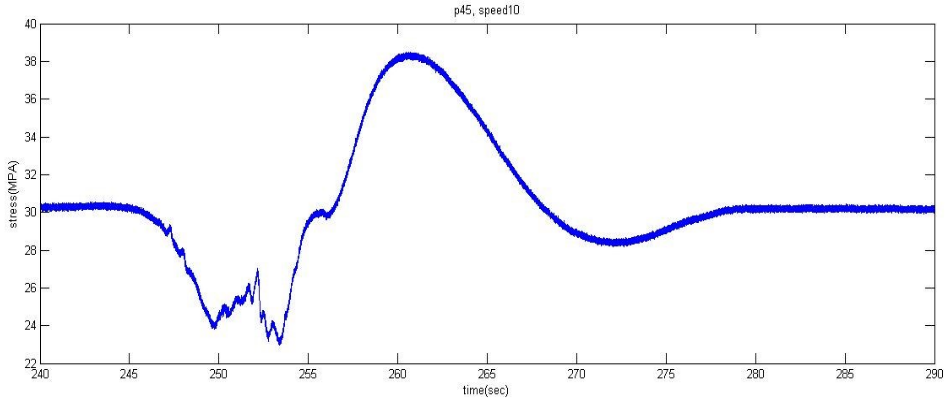


Figure(65) stress history at point 19(10km/hr)

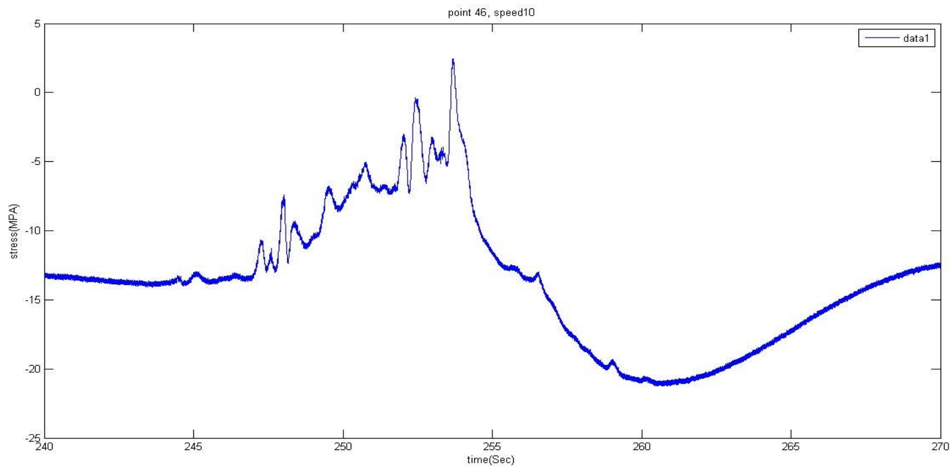


Figure(66) stress history at point 20(10km/hr)

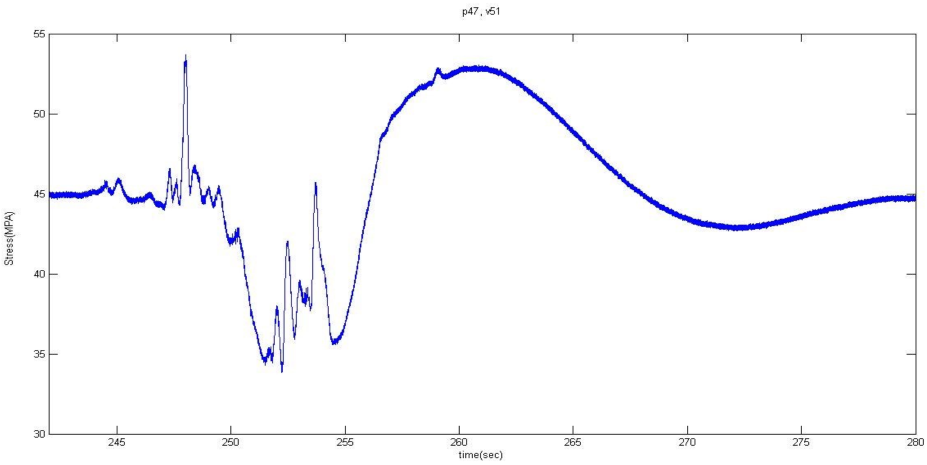
B-Support region



Figure(67) stress history at point 45(10km/hr)



Figure(68) stress history at point 46(10km/hr)

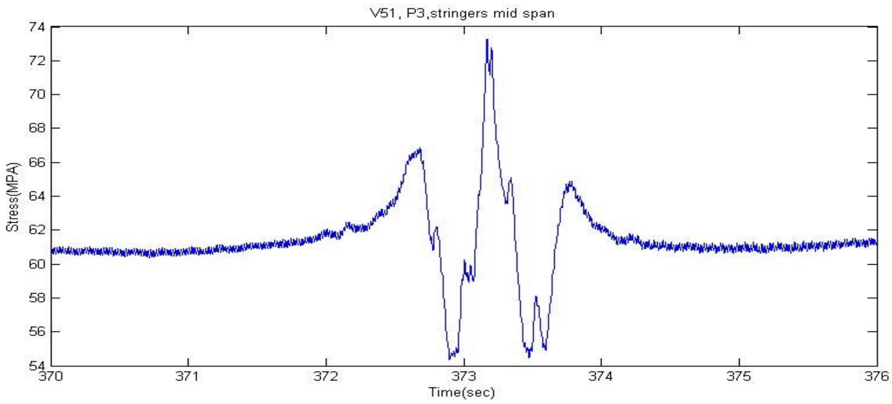


Figure(69) stress history at point 47(10km/hr)

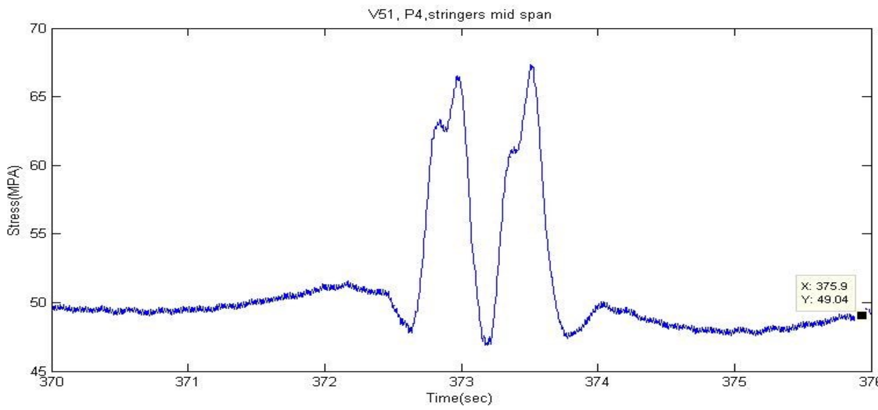
3.3.3 Graphs for velocity (51km/hr)

3.3.3.1 Stringers

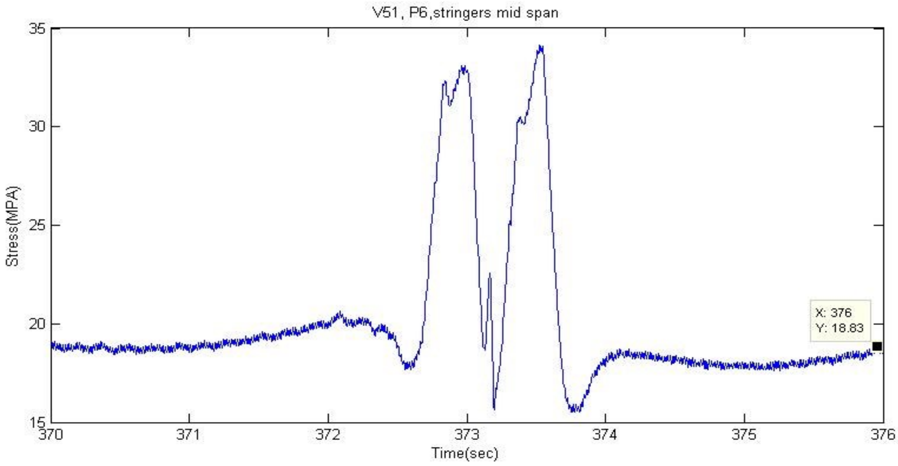
A- Mid span region



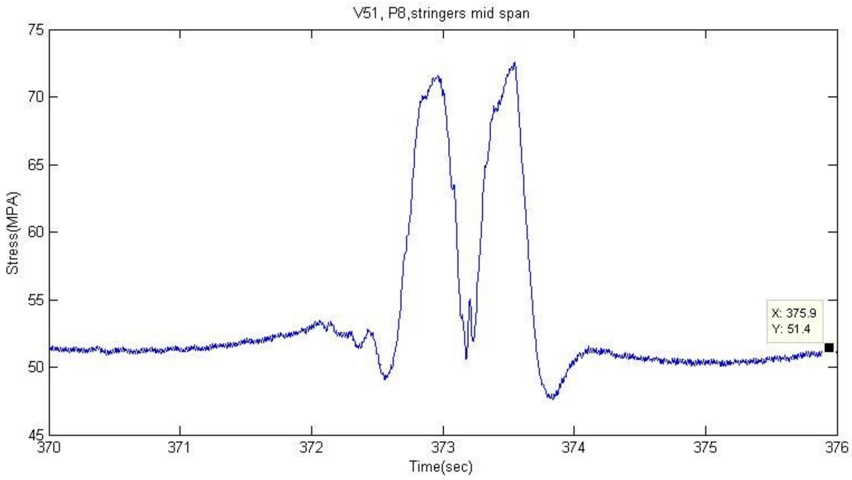
Figure(70) stress history at point 3(51km/hr)



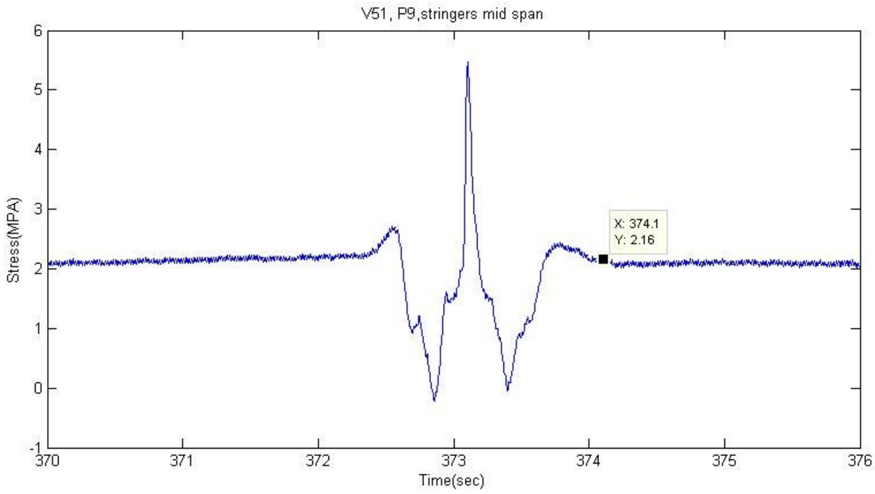
Figure(71) stress history at point 4(51km/hr)



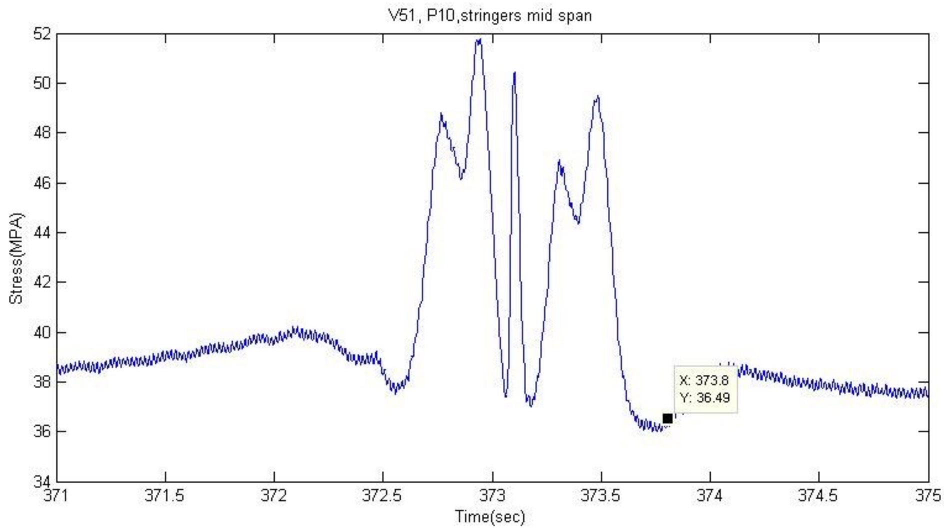
Figure(72) stress history at point 6(51km/hr)



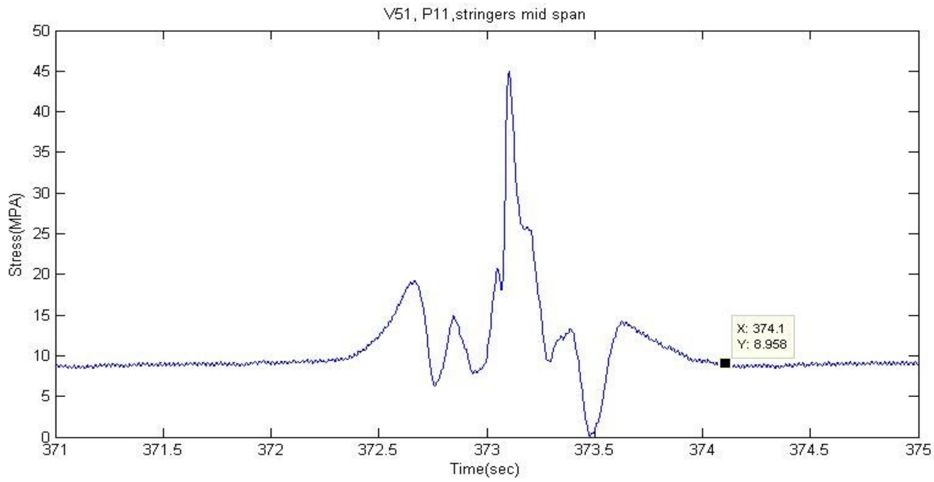
Figure(73) stress history at point 8(51km/hr)



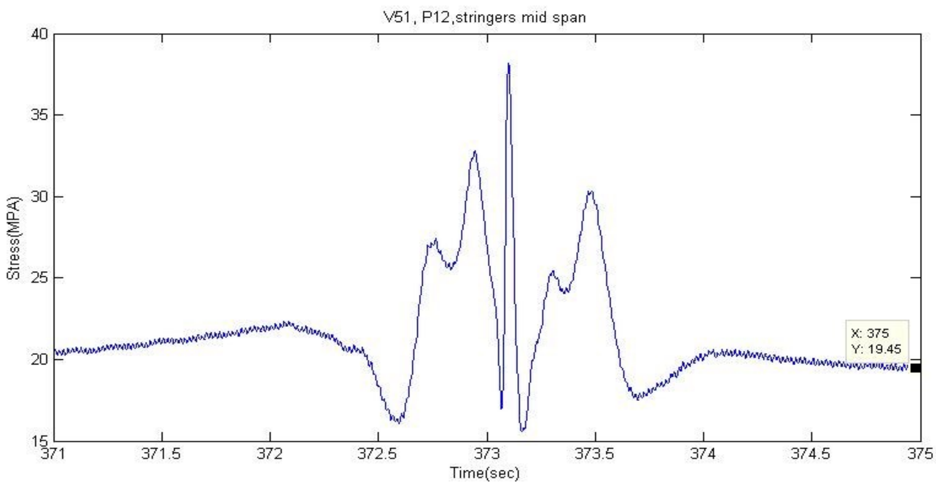
Figure(74) stress history at point 9(51km/hr)



Figure(75) stress history at point 10(51km/hr)

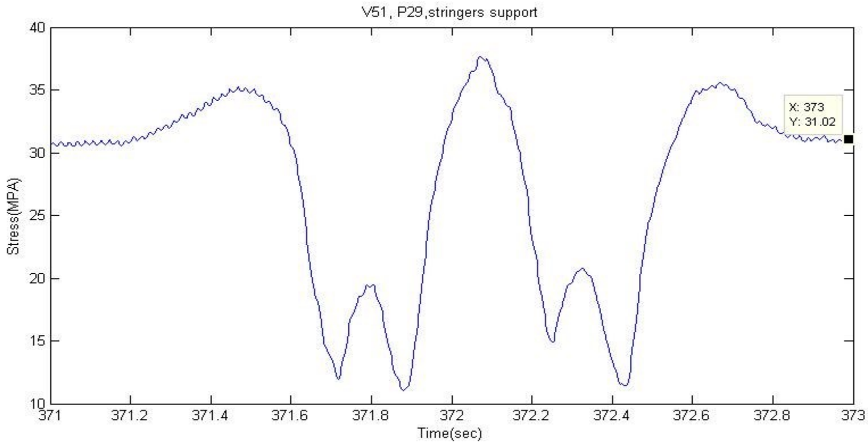


Figure(76) stress history at point 11(51km/hr)

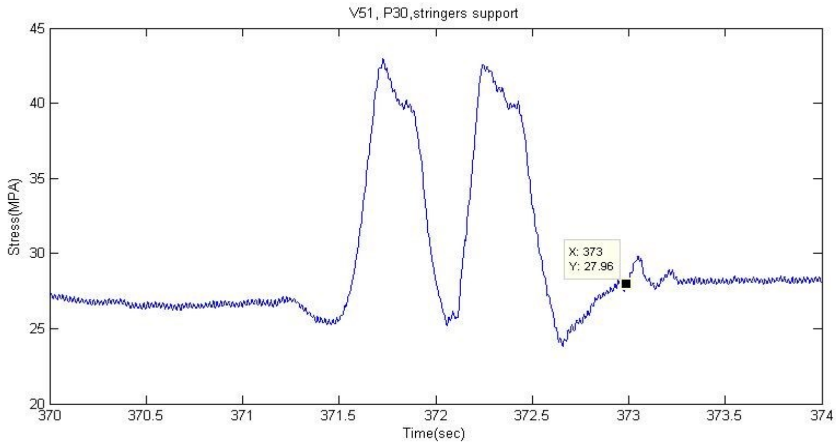


Figure(77) stress history at point 12(51km/hr)

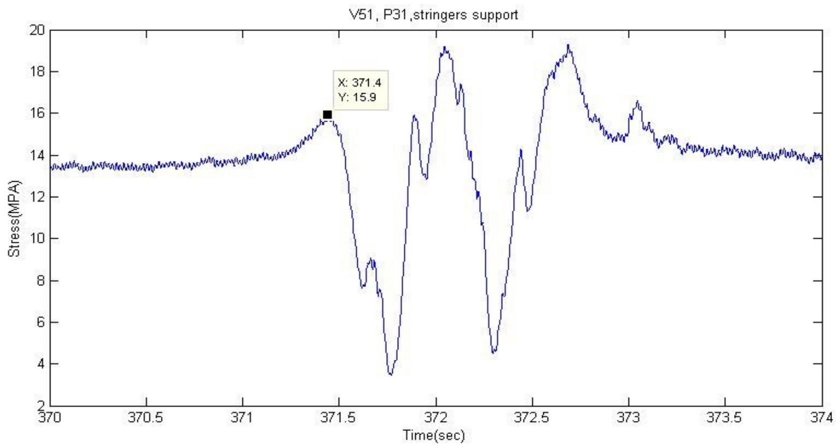
B- Support region



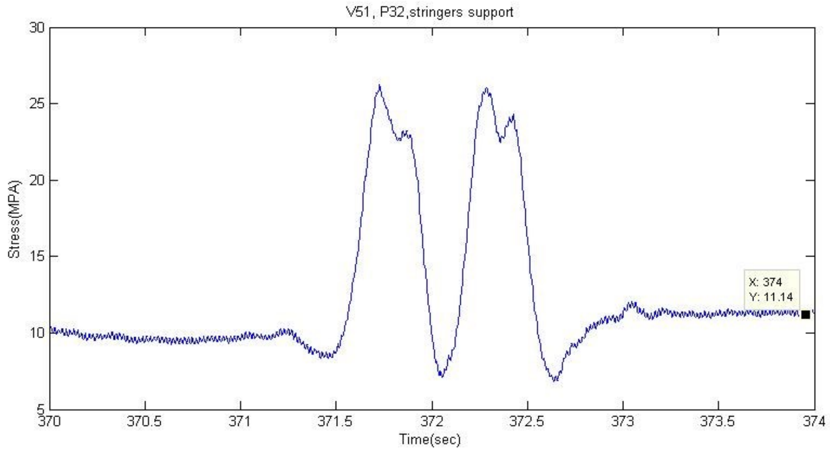
Figure(78) stress history at point 29(51km/hr)



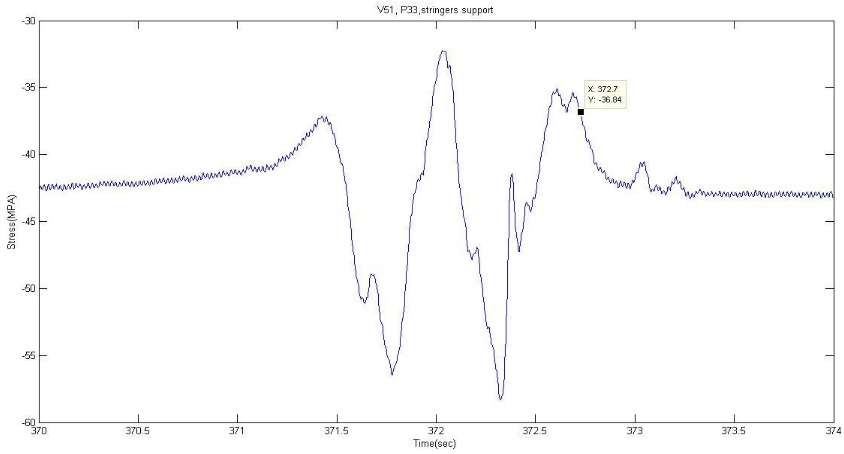
Figure(79) stress history at point 30(51km/hr)



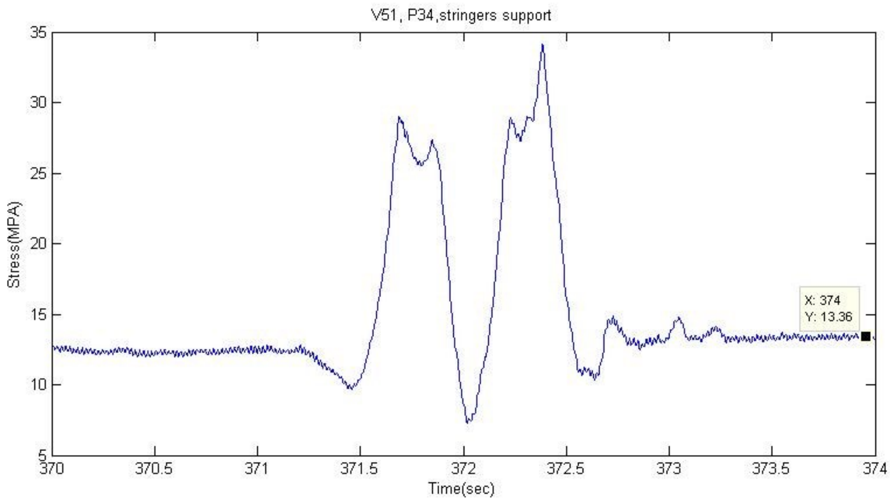
Figure(80) stress history at point 31(51km/hr)



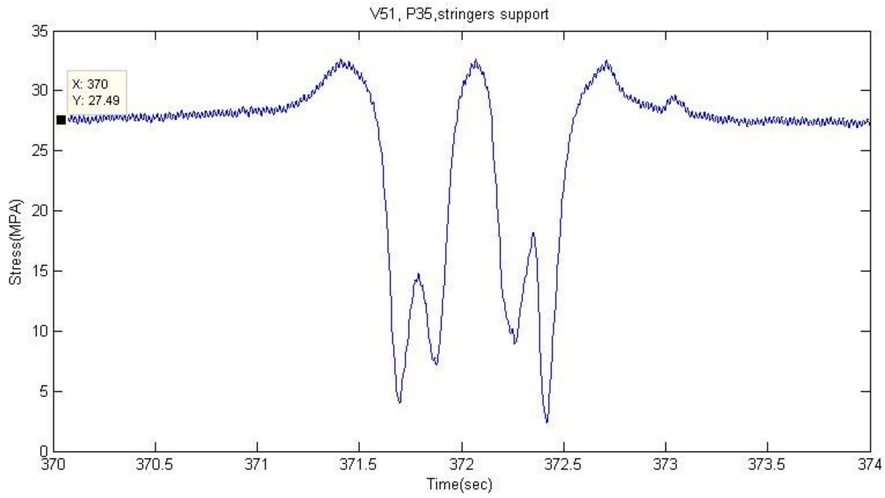
Figure(81) stress history at point 32(51km/hr)



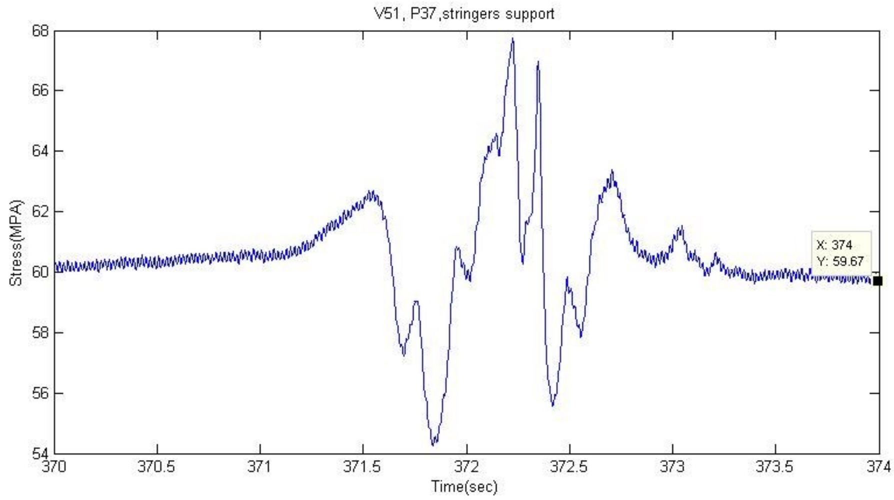
Figure(82) stress history at point 33(51km/hr)



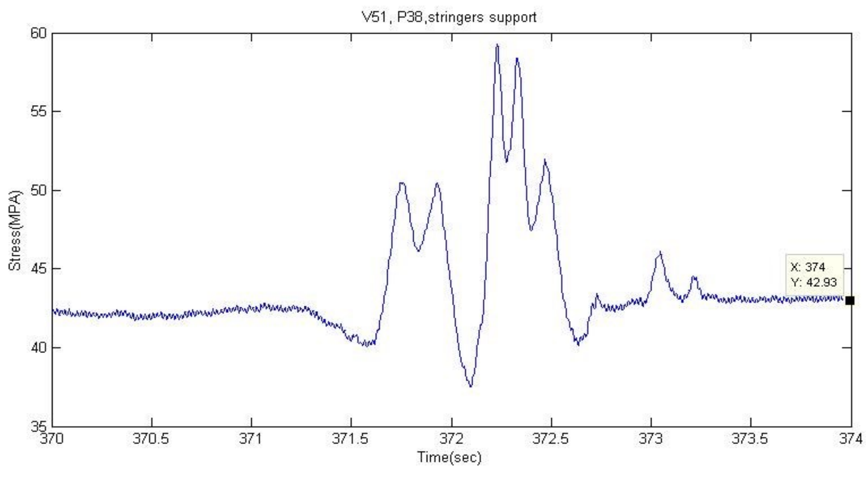
Figure(83) stress history at point 34(51km/hr)



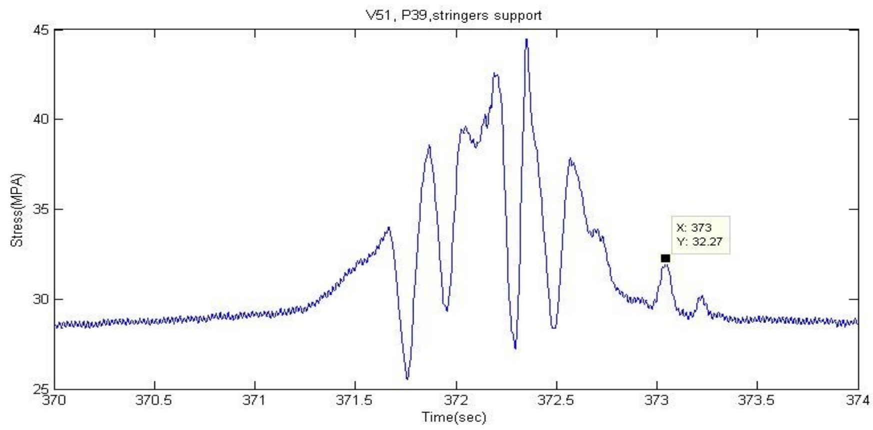
Figure(84) stress history at point 35(51km/hr)



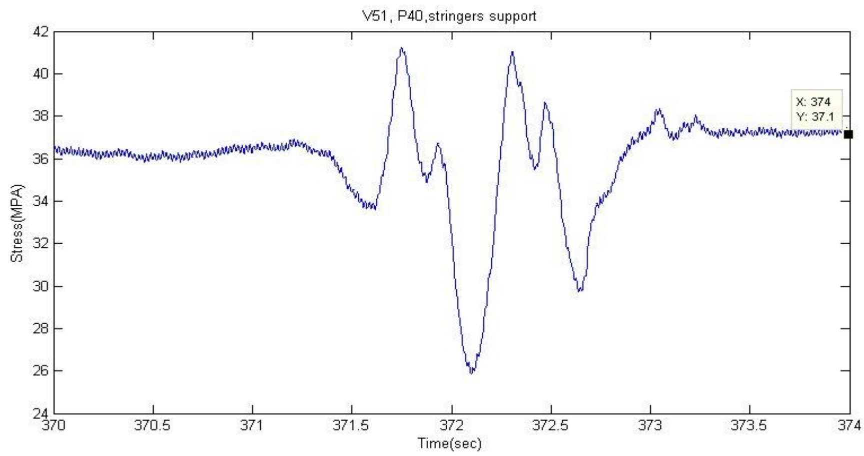
Figure(85) stress history at point 37(51km/hr)



Figure(86) stress history at point 38(51km/hr)



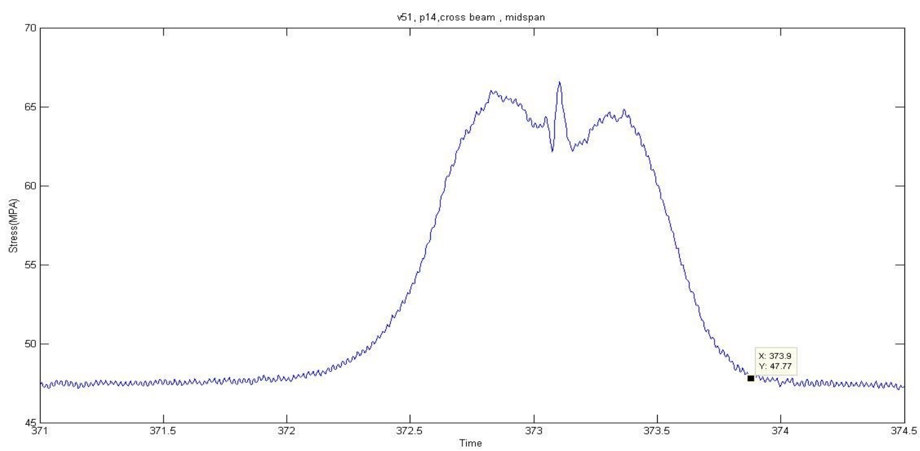
Figure(87) stress history at point 39(51km/hr)



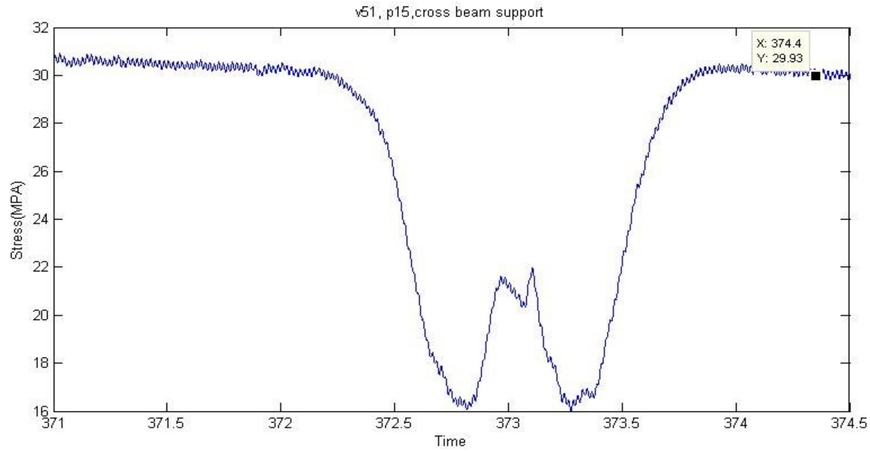
Figure(88) stress history at point 40(51km/hr)

3.3.3.2 Cross beams

A- Mid- span region

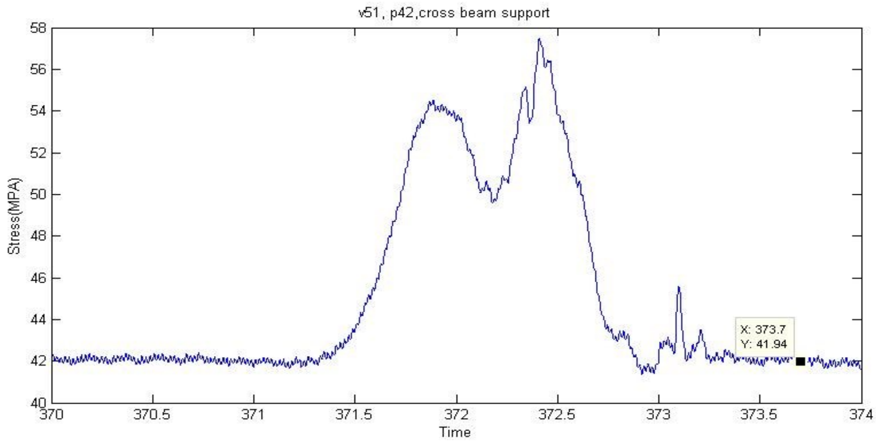


Figure(89) stress history at point 14(51km/hr)

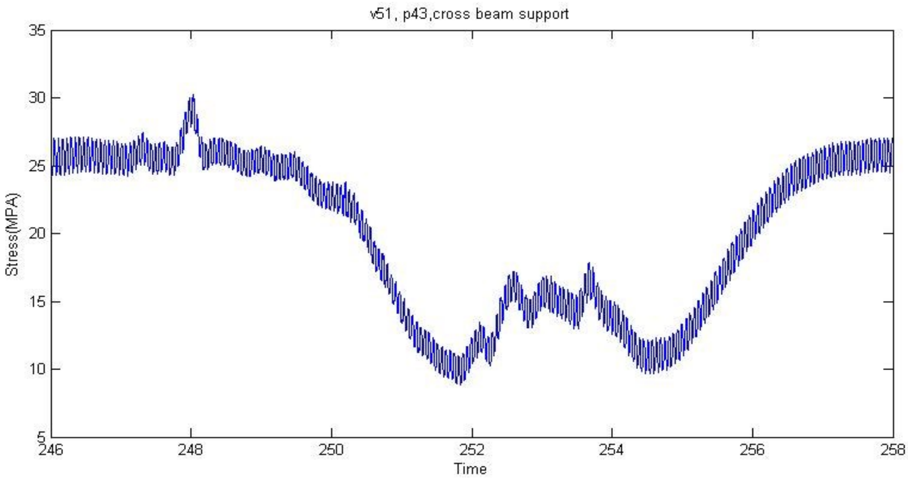


Figure(90) stress history at point 15(51km/hr)

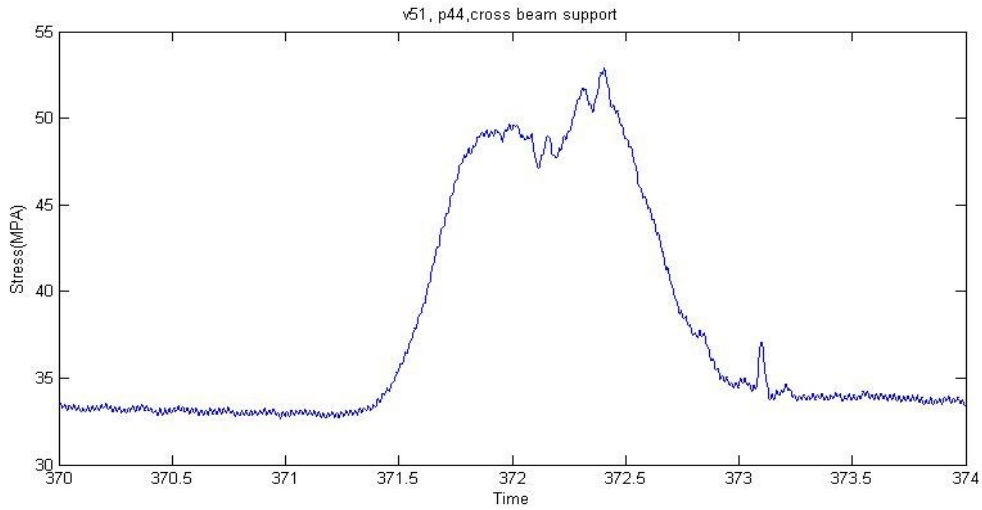
B- Support- region



Figure(91) stress history at point 42(51km/hr)



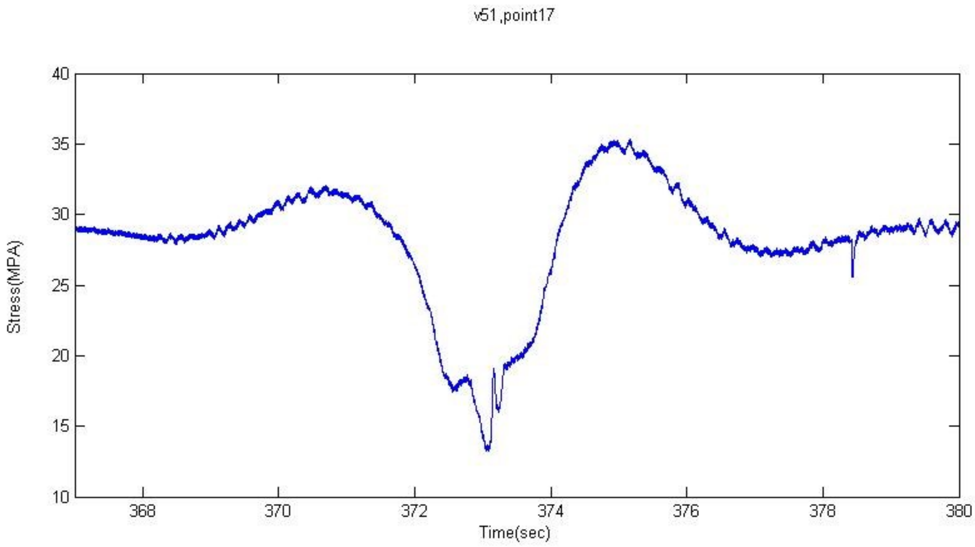
Figure(92) stress history at point 43(51km/hr)



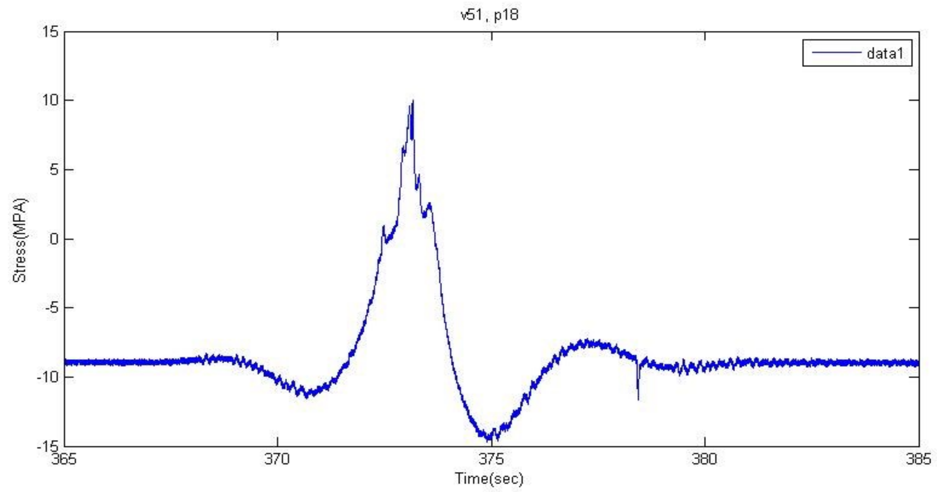
Figure(93) stress history at point 44(51km/hr)

3.3.3.3 Main Girders

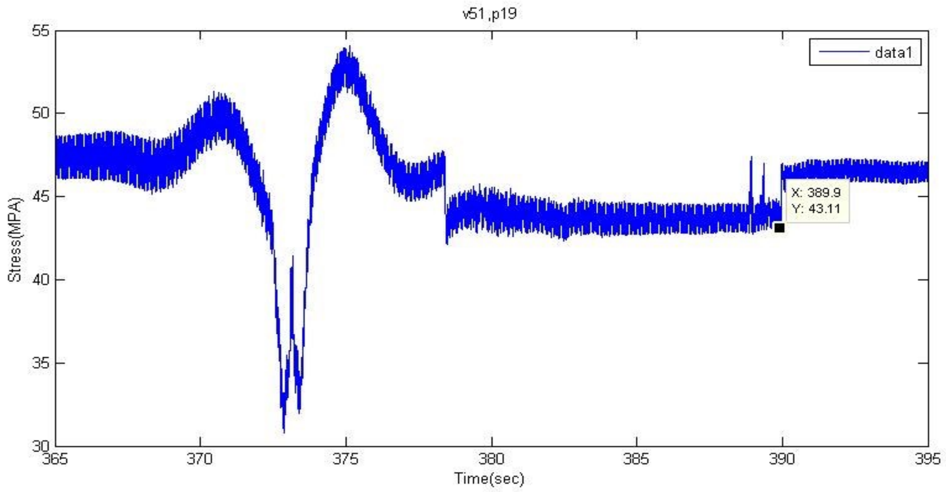
A- Mid- span region



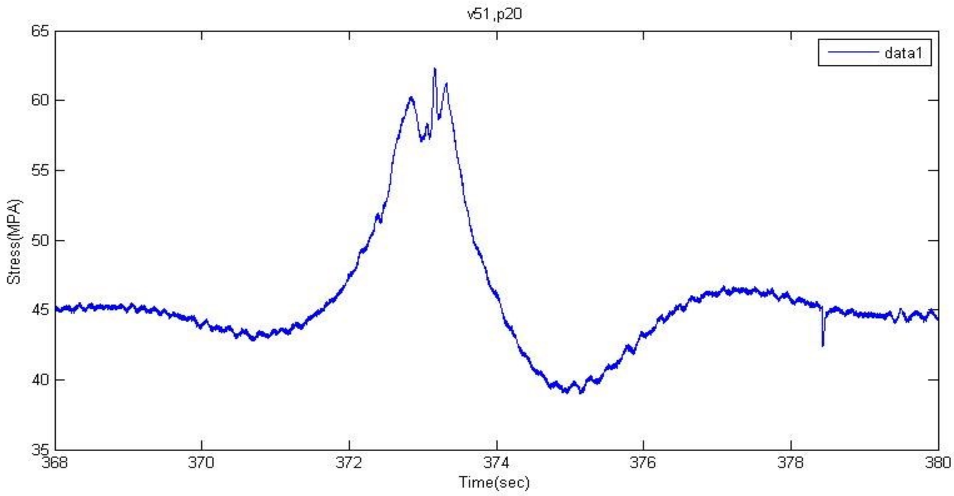
Figure(94) stress history at point 17(51km/hr)



Figure(95) stress history at point 18(51km/hr)

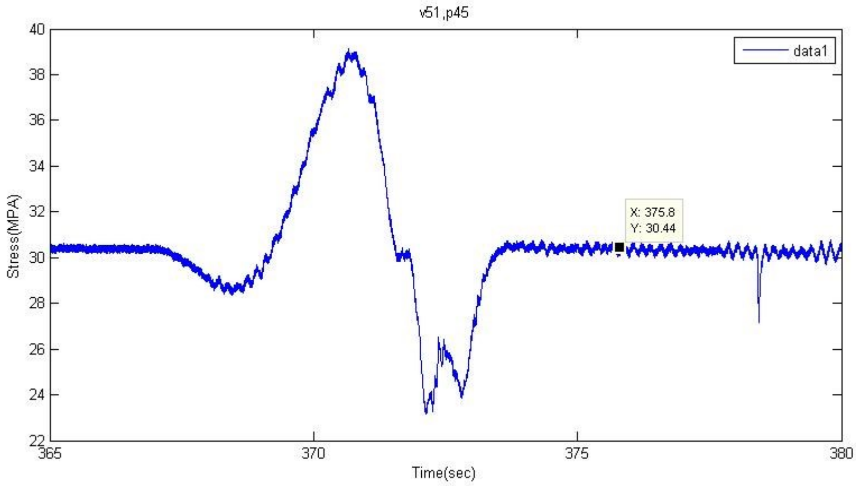


Figure(96) stress history at point 19(51km/hr)

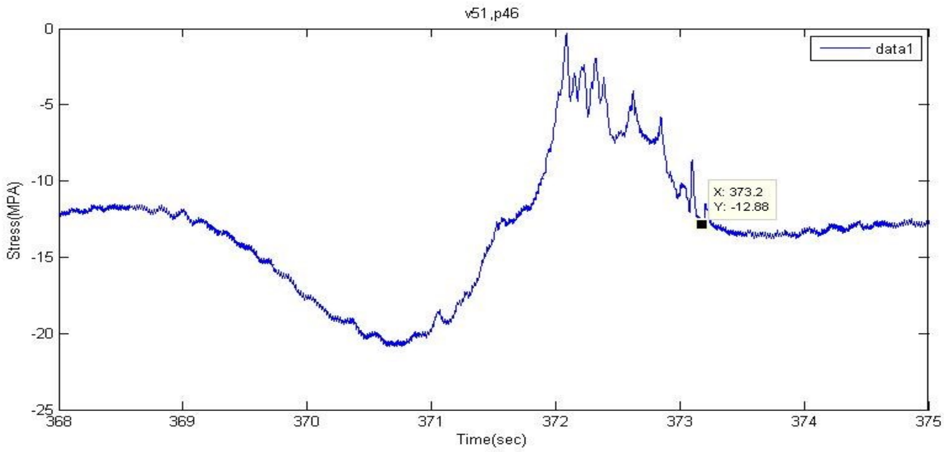


Figure(97) stress history at point 20(51km/hr)

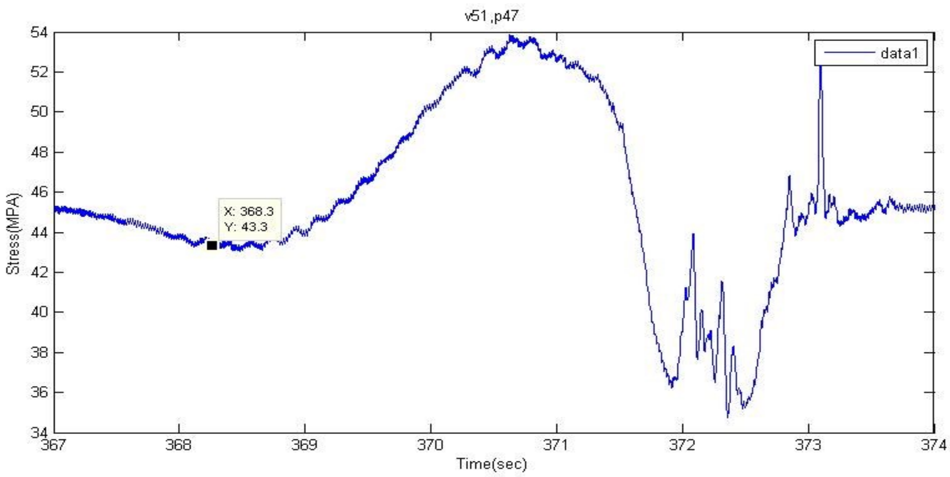
B- Support- region



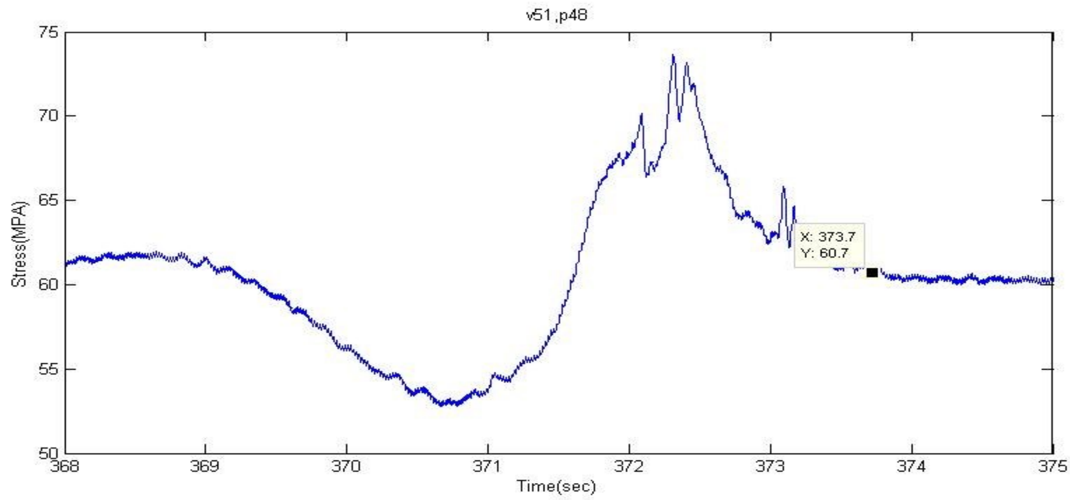
Figure(98) stress history at point 45(51km/hr)



Figure(99) stress history at point 46(51km/hr)



Figure(100) stress history at point 47(51km/hr)

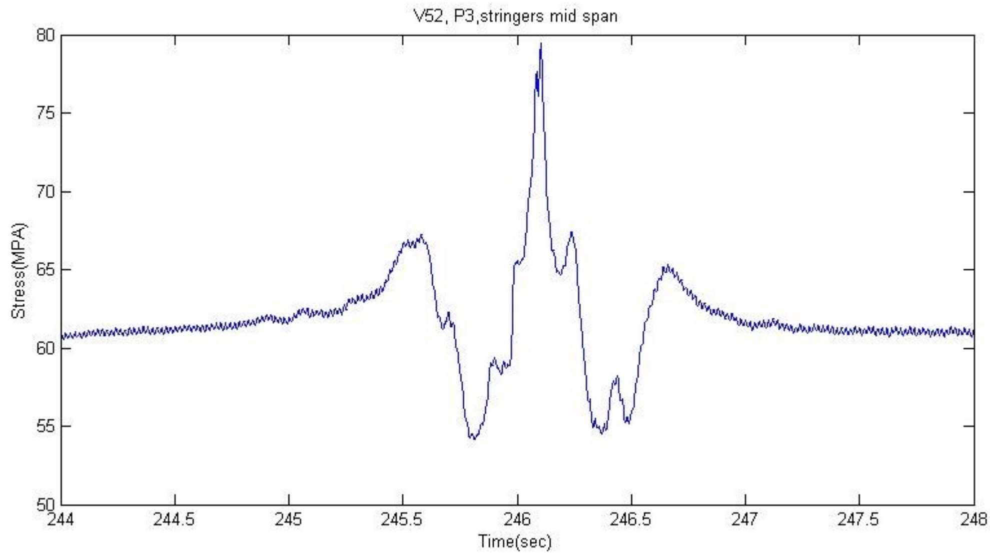


Figure(101) stress history at point 48(51km/hr)

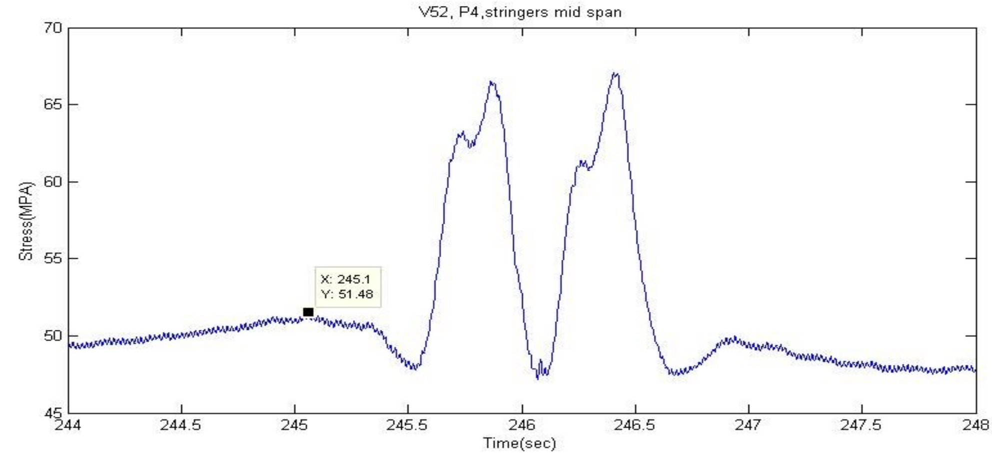
3.3.4 Graphs for velocity (52km/hr)

3.3.4.1 Stringers

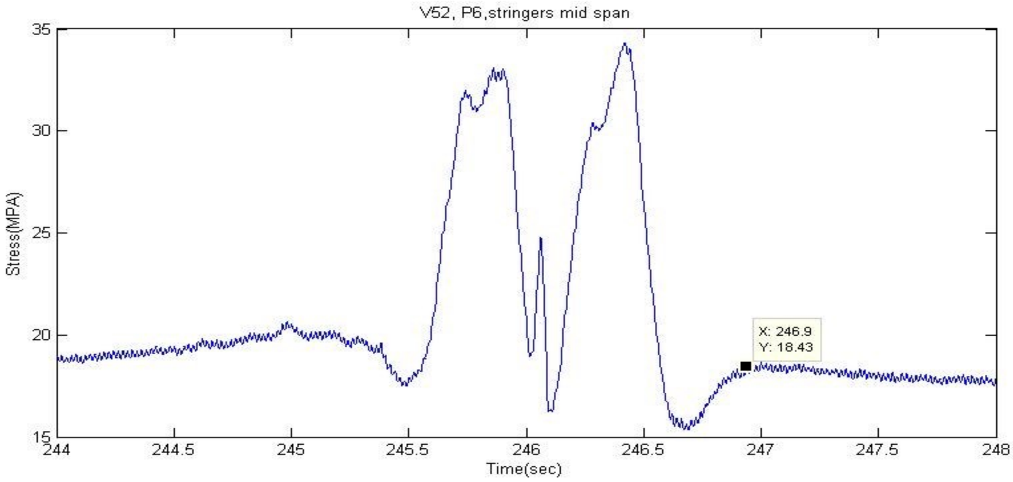
A- Mid span region



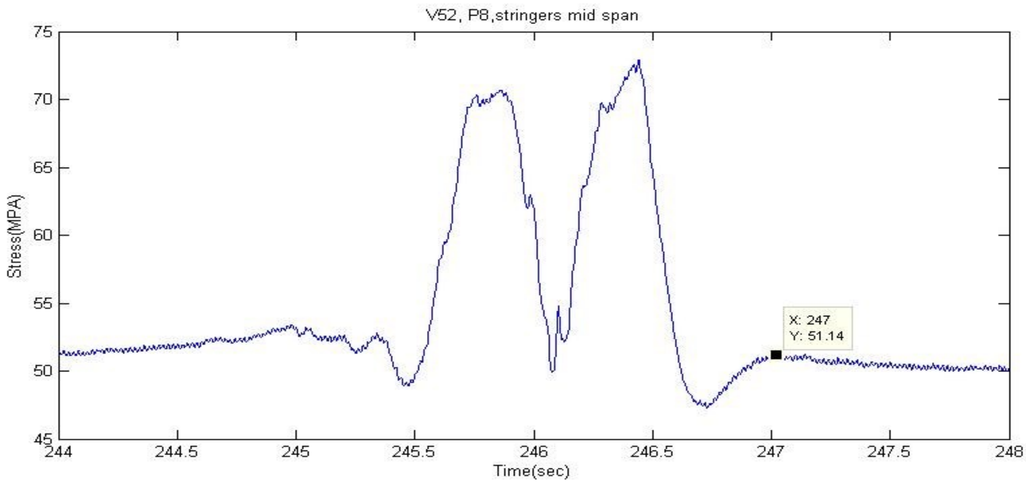
Figure(102) stress history at point 3(52km/hr)



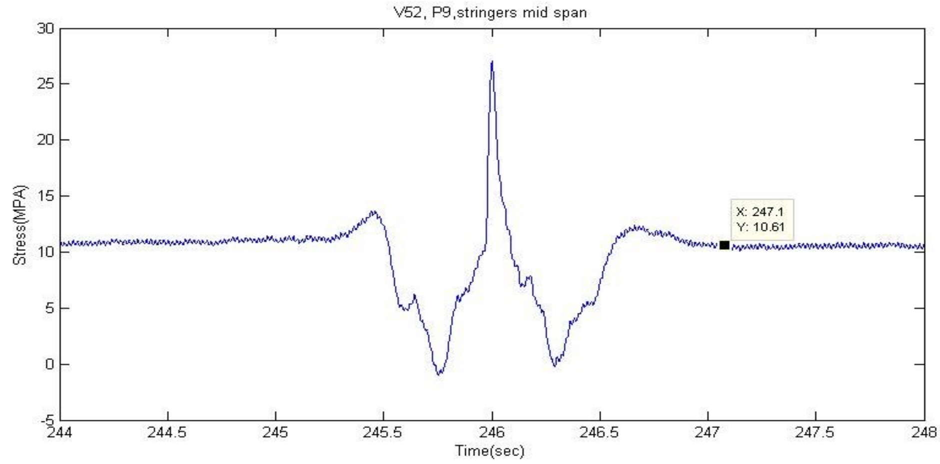
Figure(103) stress history at point 4(52km/hr)



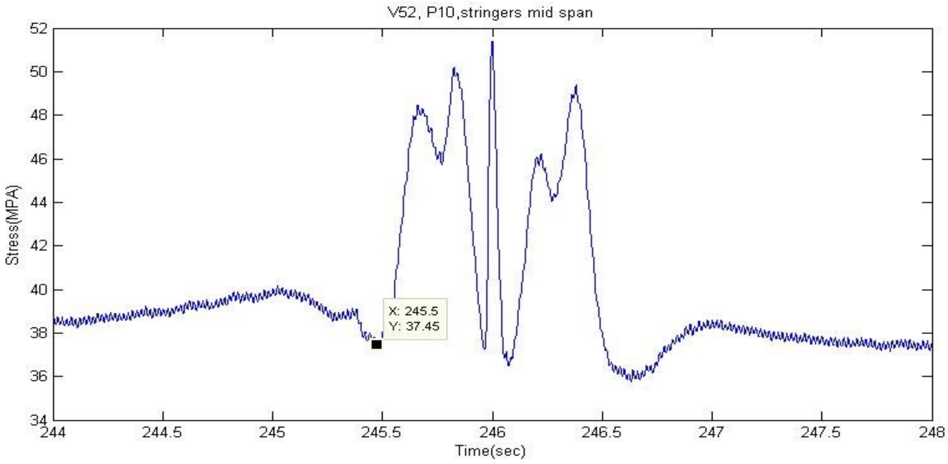
Figure(104) stress history at point 6(52km/hr)



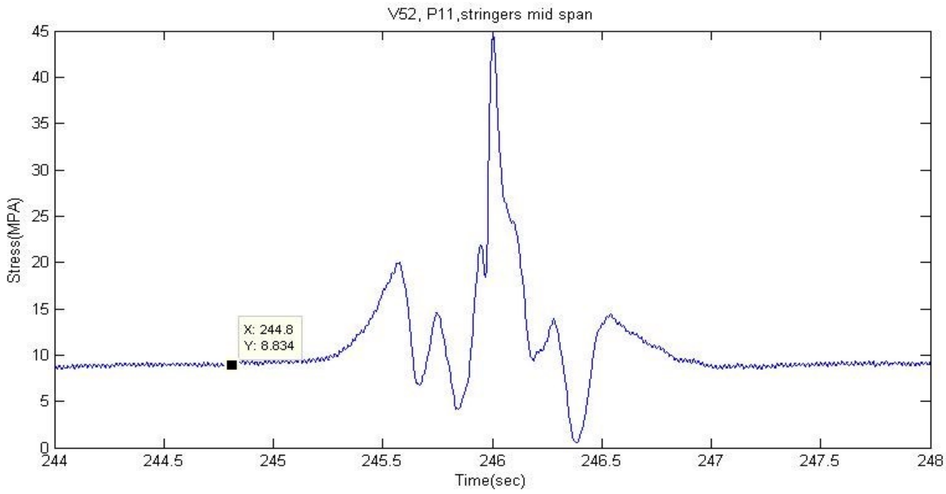
Figure(105) stress history at point 8(52km/hr)



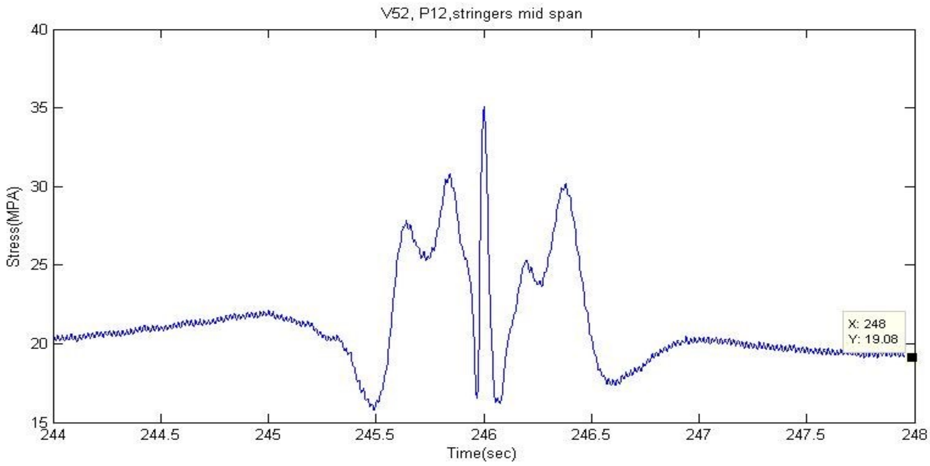
Figure(106) stress history at point 9(52km/hr)



Figure(107) stress history at point 10(52km/hr)

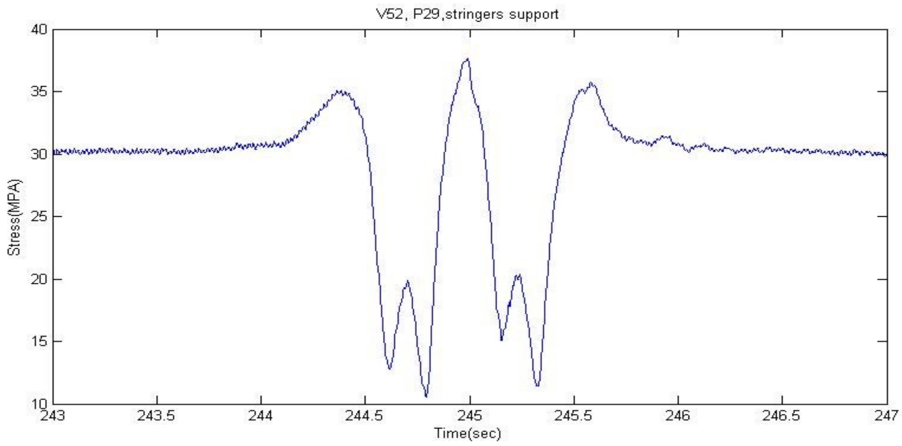


Figure(108) stress history at point 11(52km/hr)

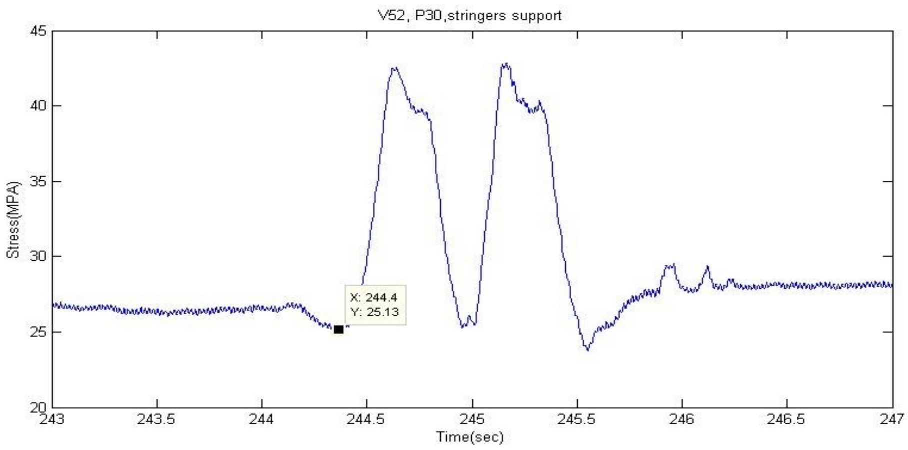


Figure(109) stress history at point 12(52km/hr)

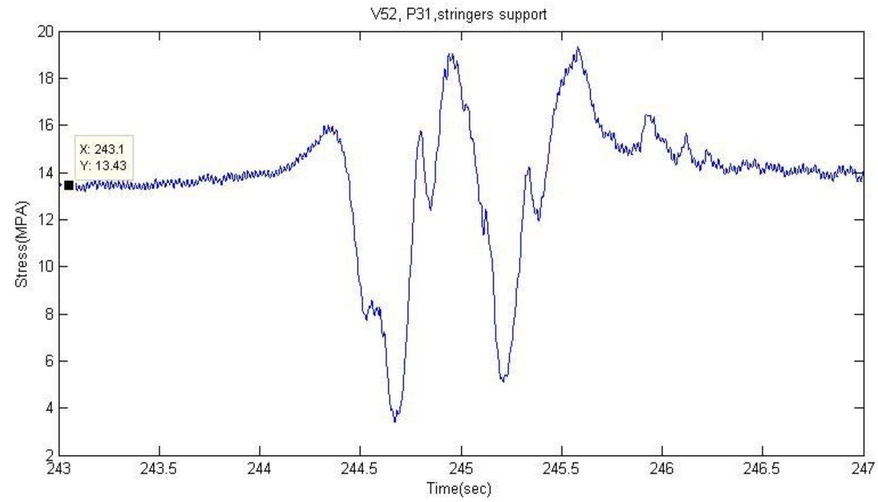
B- support region



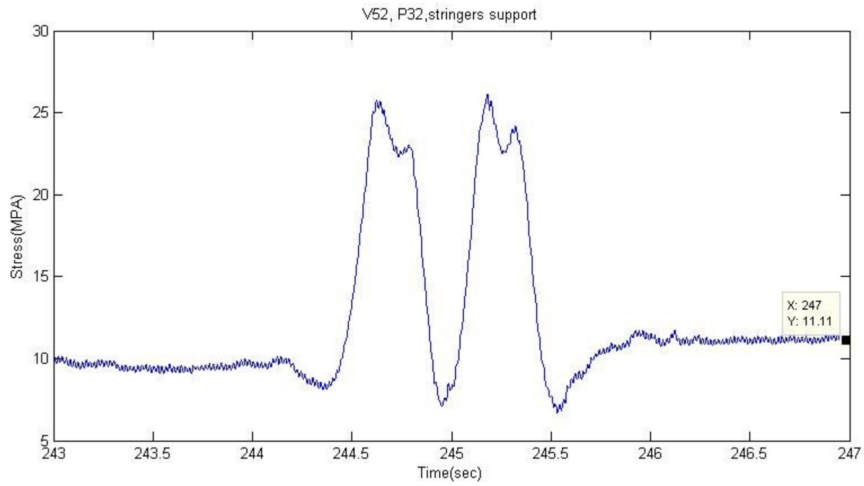
Figure(110) stress history at point 29(52km/hr)



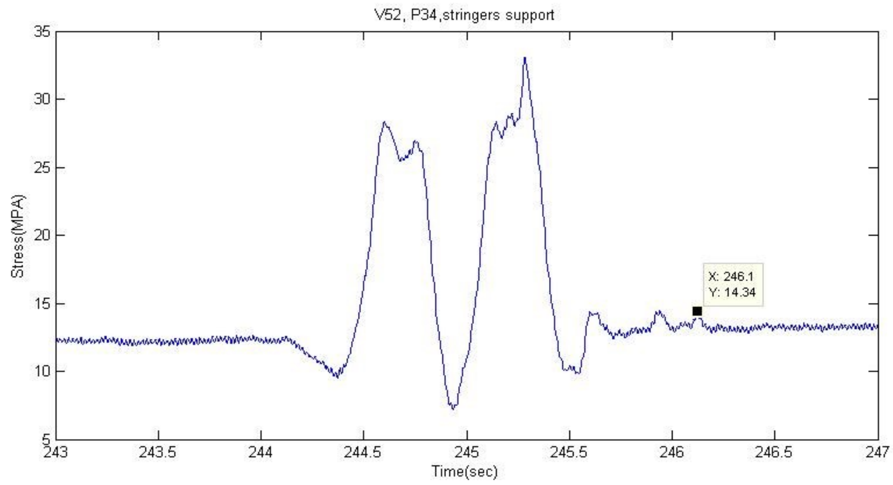
Figure(111) stress history at point 30(52km/hr)



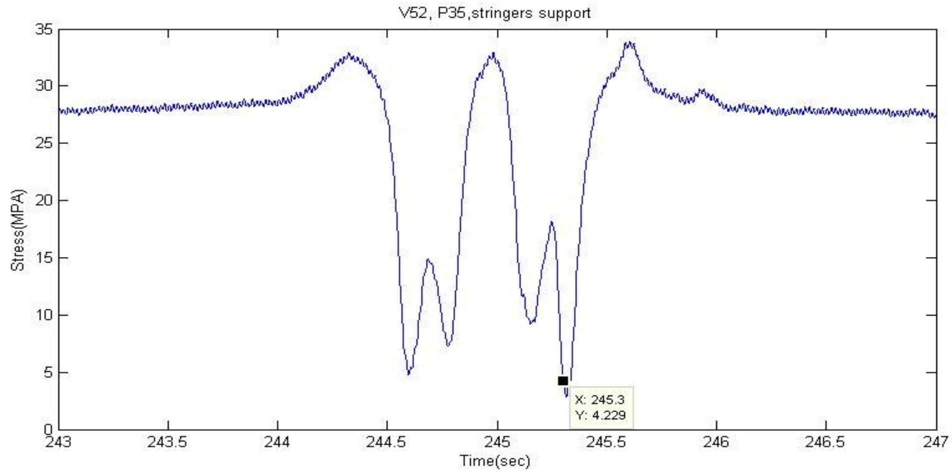
Figure(112) stress history at point 31(52km/hr)



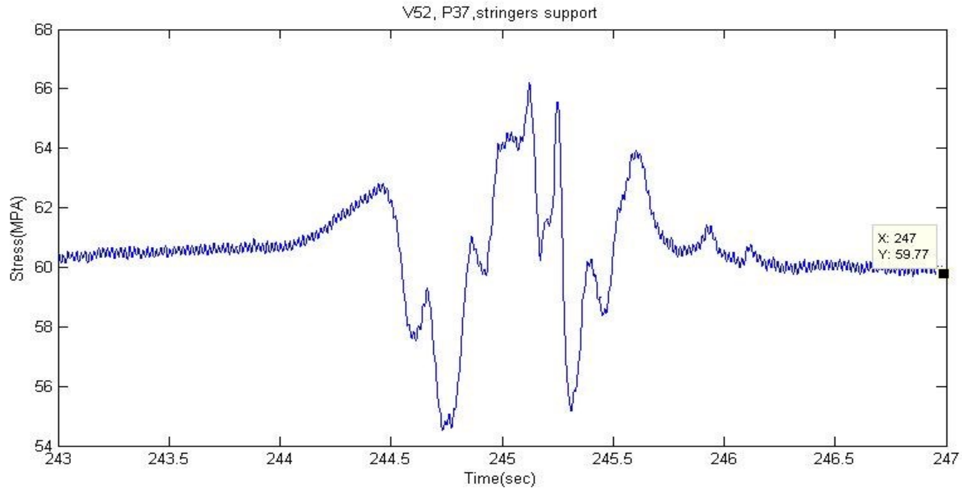
Figure(113) stress history at point 32(52km/hr)



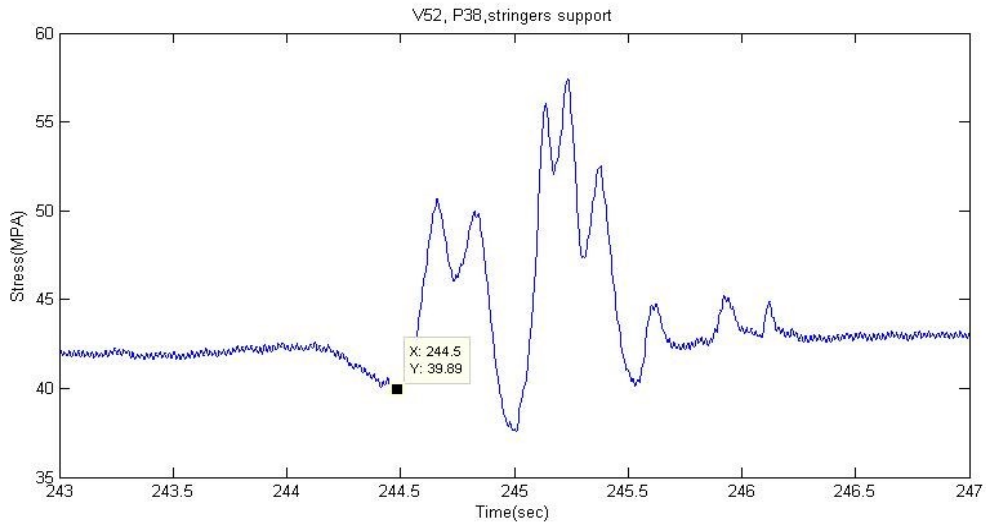
Figure(114) stress history at point 34(52km/hr)



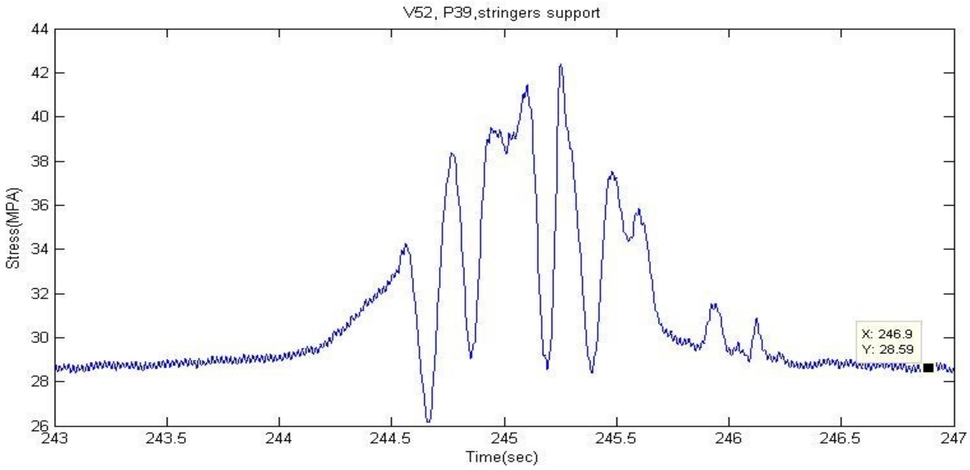
Figure(115) stress history at point 35(52km/hr)



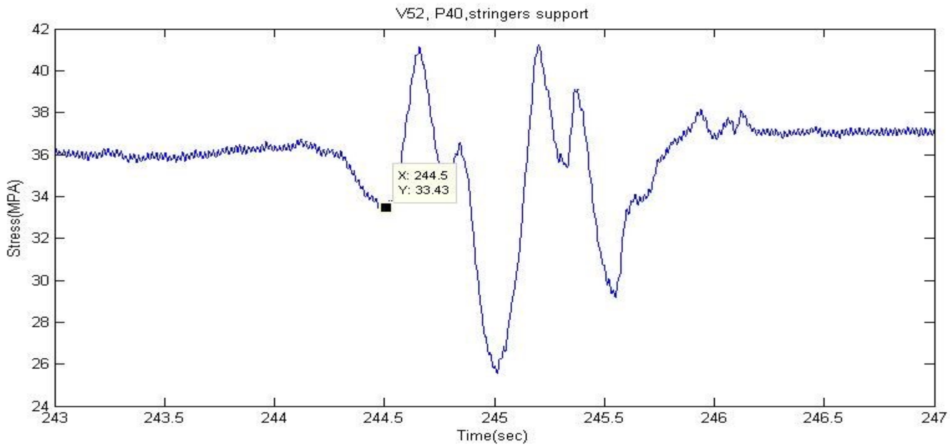
Figure(116) stress history at point 37(52km/hr)



Figure(117) stress history at point 38(52km/hr)

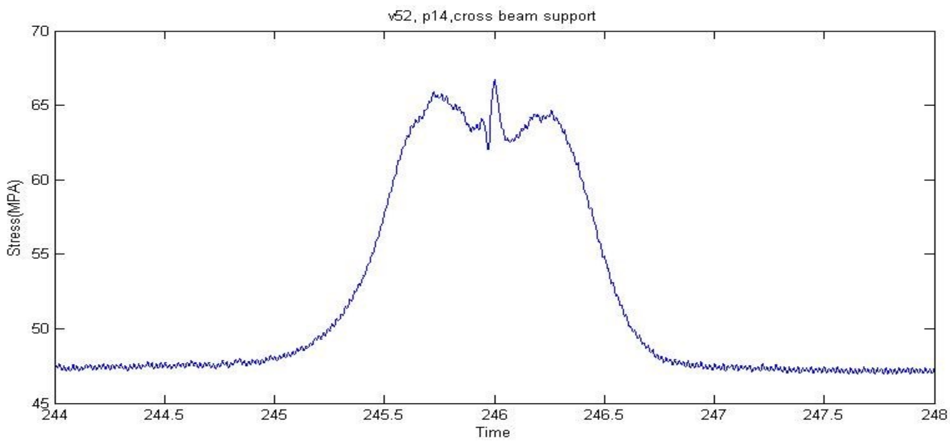


Figure(118) stress history at point 39(52km/hr)

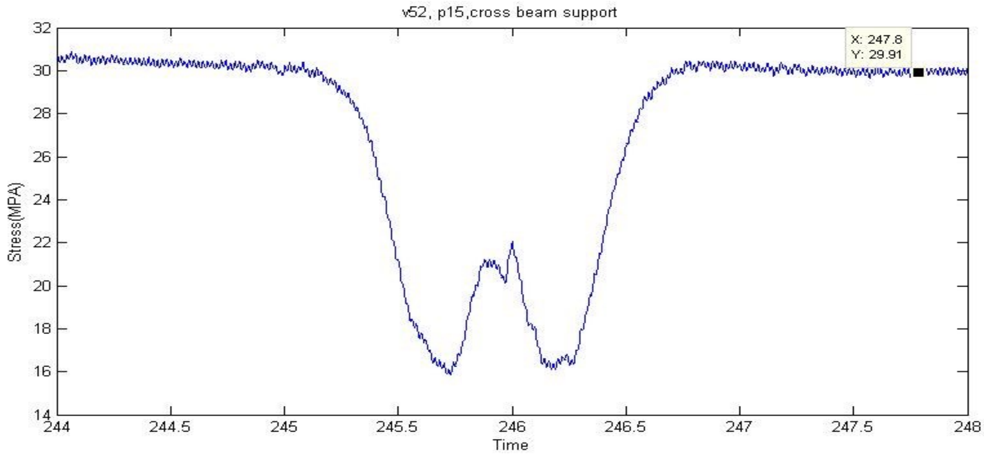


Figure(119) stress history at point 40(52km/hr)

3.3.4.2 Cross beams : A- Mid span

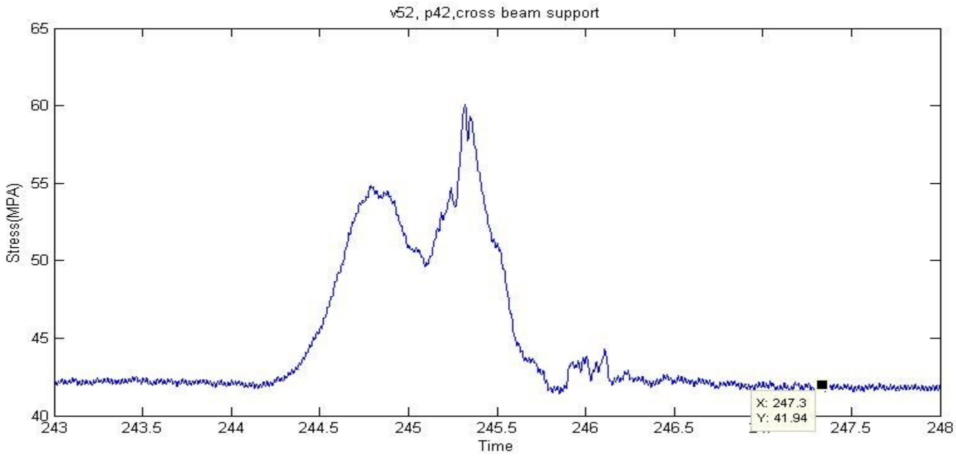


Figure(120) stress history at point 14(52km/hr)

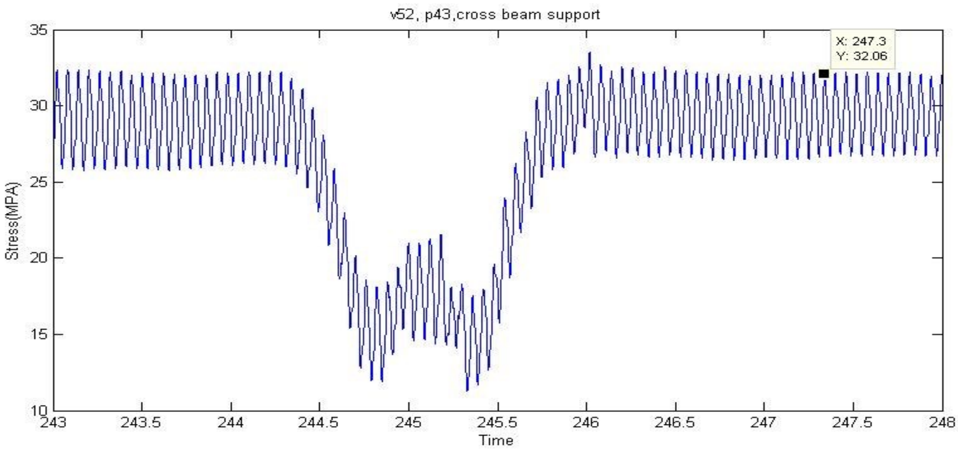


Figure(121) stress history at point 15(52km/hr)

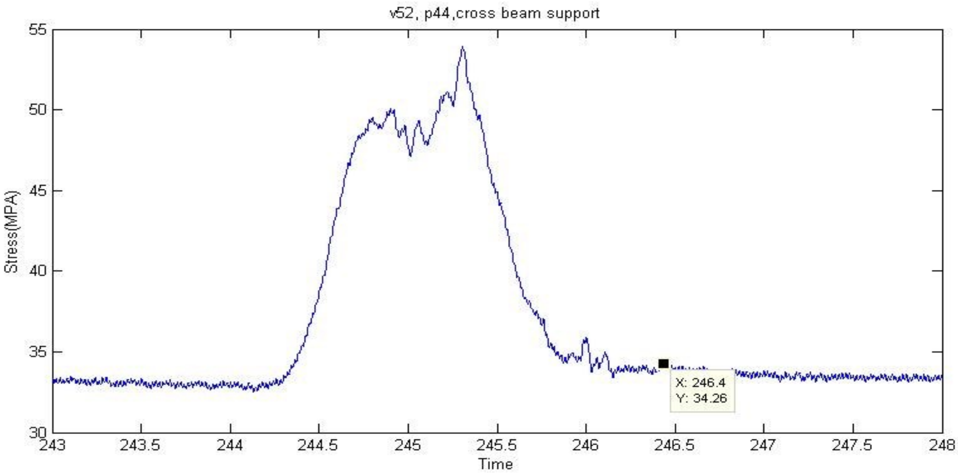
B –Support region



Figure(122) stress history at point 42(52km/hr)

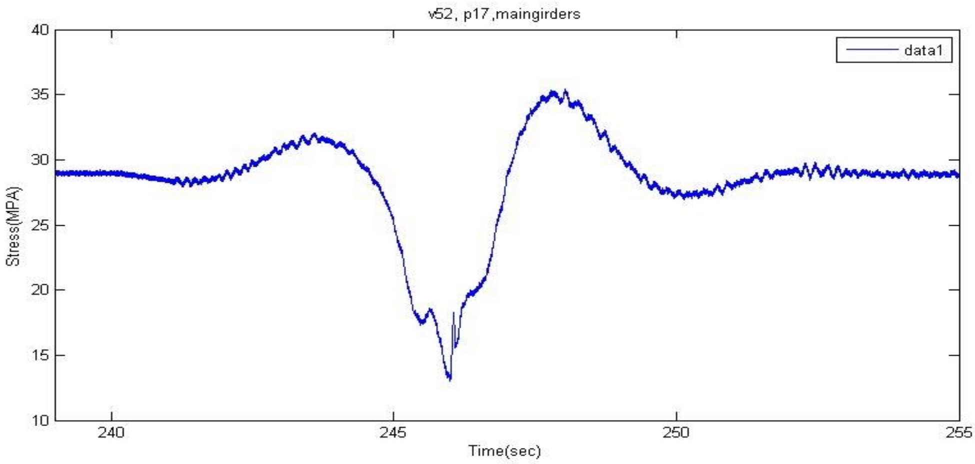


Figure(123) stress history at point 43(52km/hr)

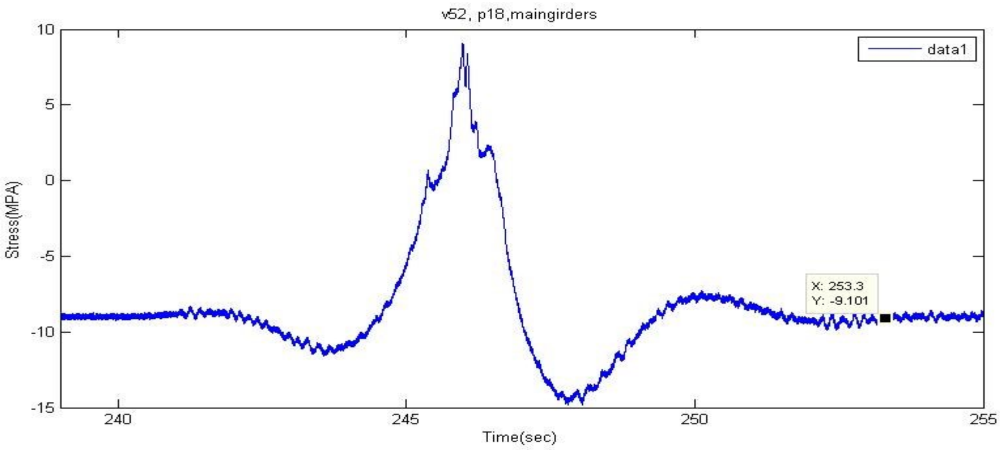


Figure(124) stress history at point 44(52km/hr)

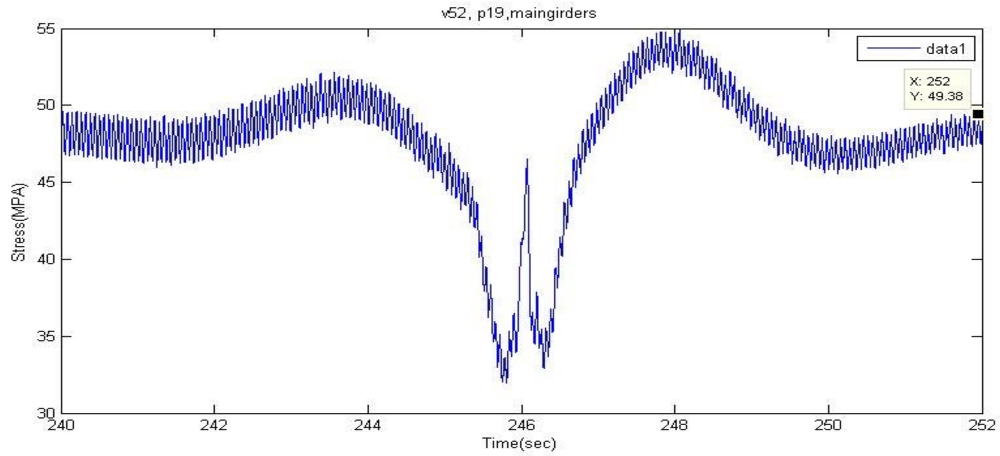
3.3.4.3 Main girders: A- Mid span



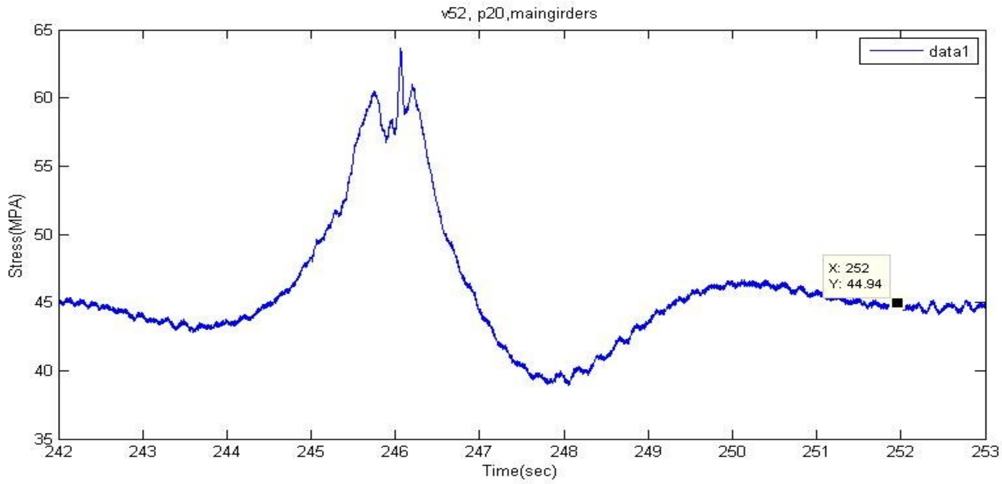
Figure(125) stress history at point 17(52km/hr)



Figure(126) stress history at point 18(52km/hr)

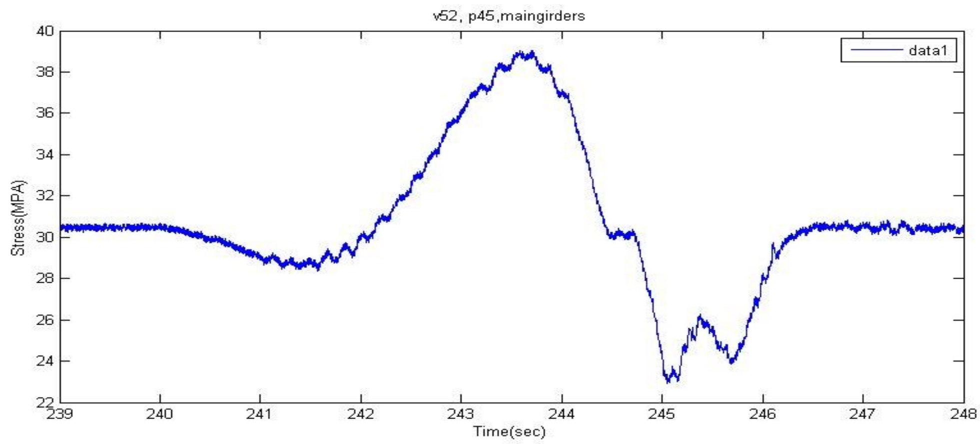


Figure(127) stress history at point 19(52km/hr)

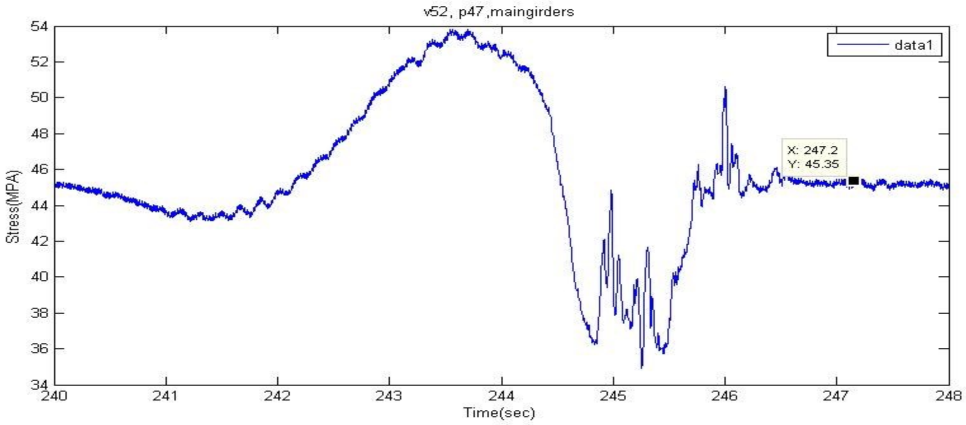


Figure(128) stress history at point 20(52km/hr)

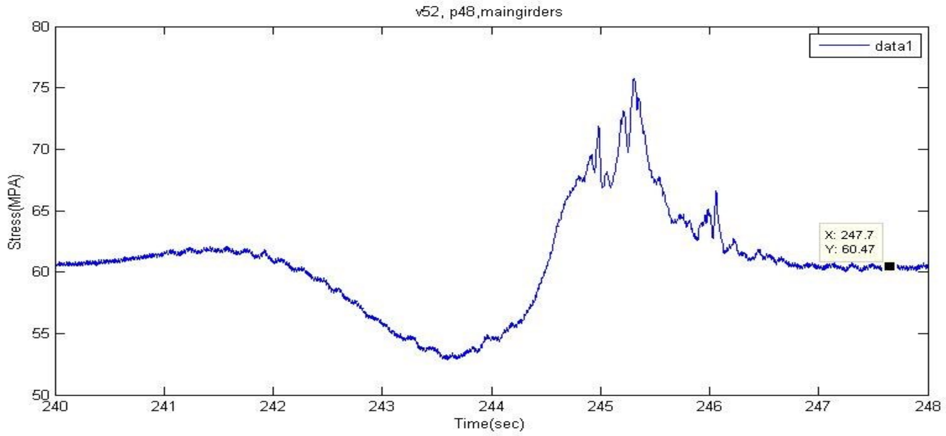
B- Support region



Figure(129) stress history at point 45(52km/hr)



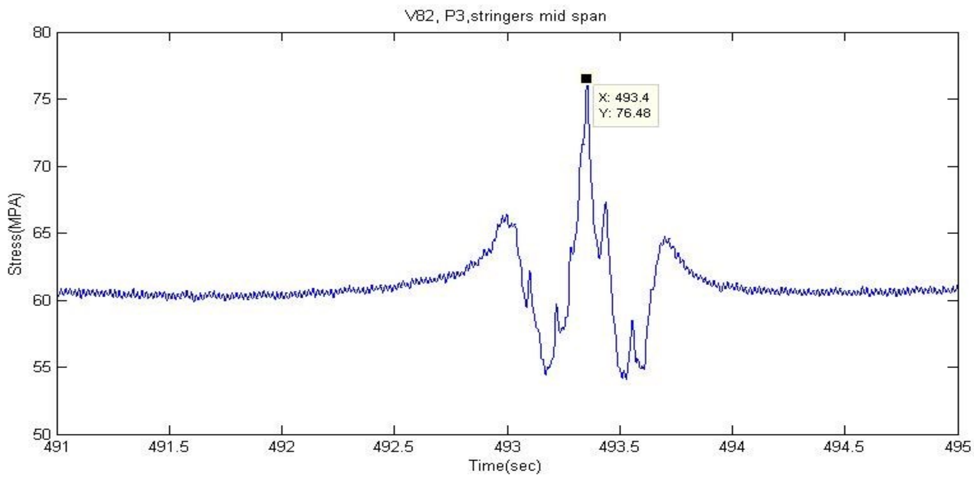
Graph(130) stress history at point 47(52km/hr)



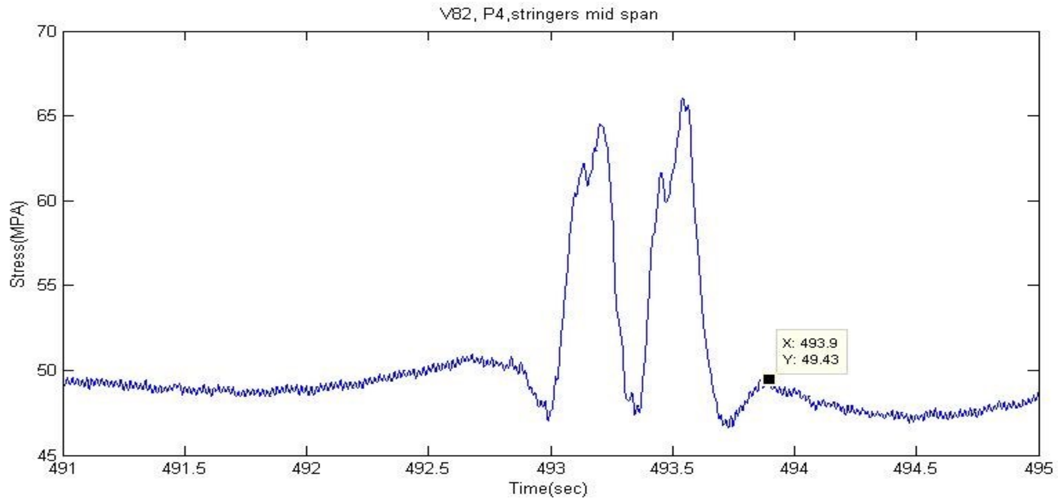
Figure(131) stress history at point 48(52km/hr)

3.3.5 Graphs for velocity (82km/hr)

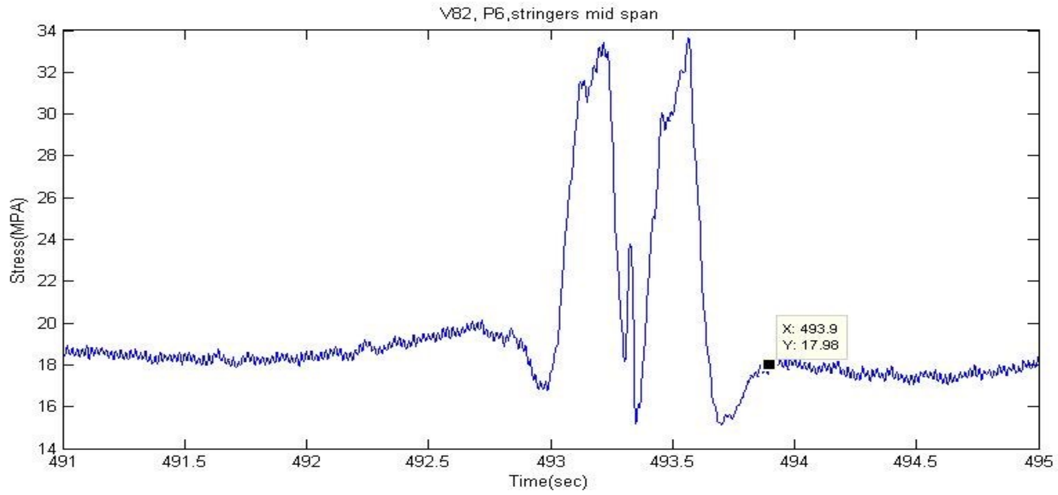
3.3.5.1 Stringers : A- Mid span region



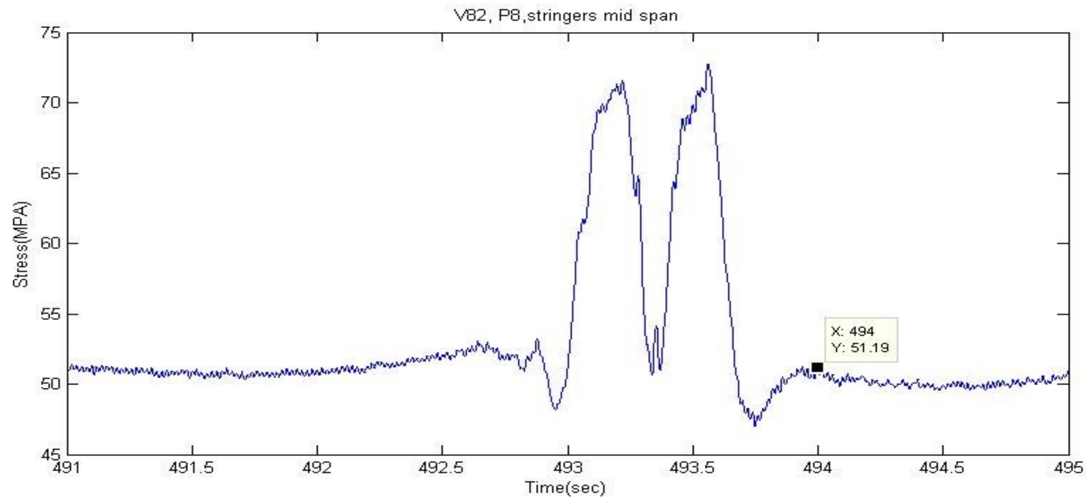
Figure(132) stress history at point 3(82km/hr)



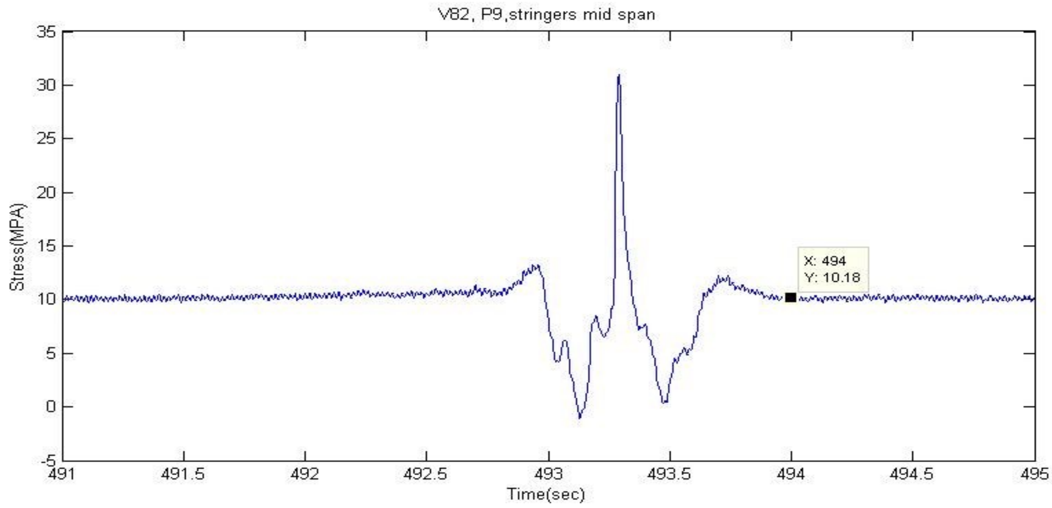
Figure(133) stress history at point 4(82km/hr)



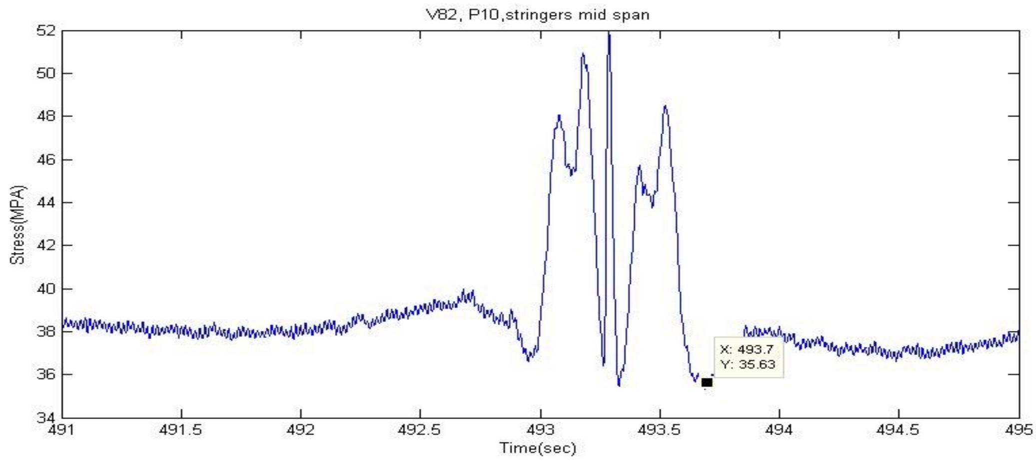
Figure(134) stress history at point 6(82km/hr)



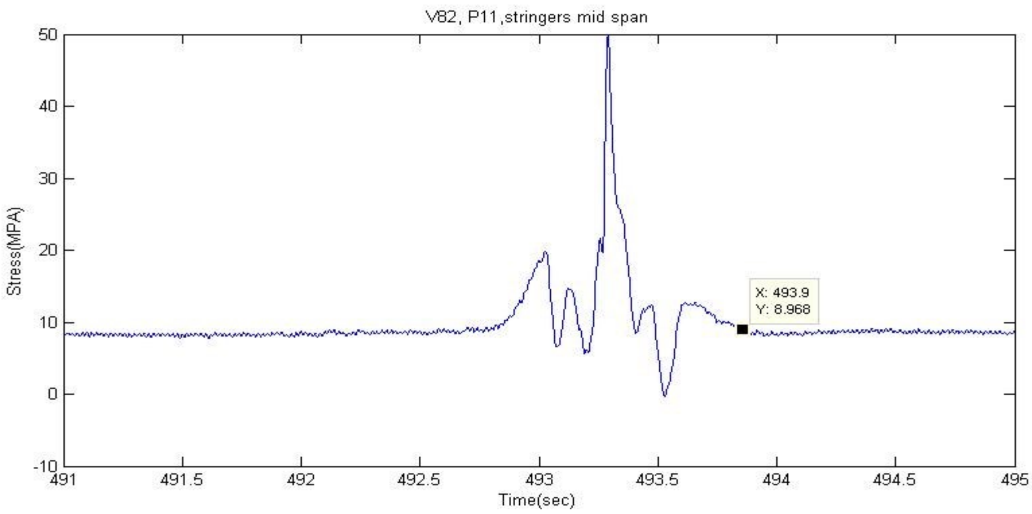
Figure(135) stress history at point 8(82km/hr)



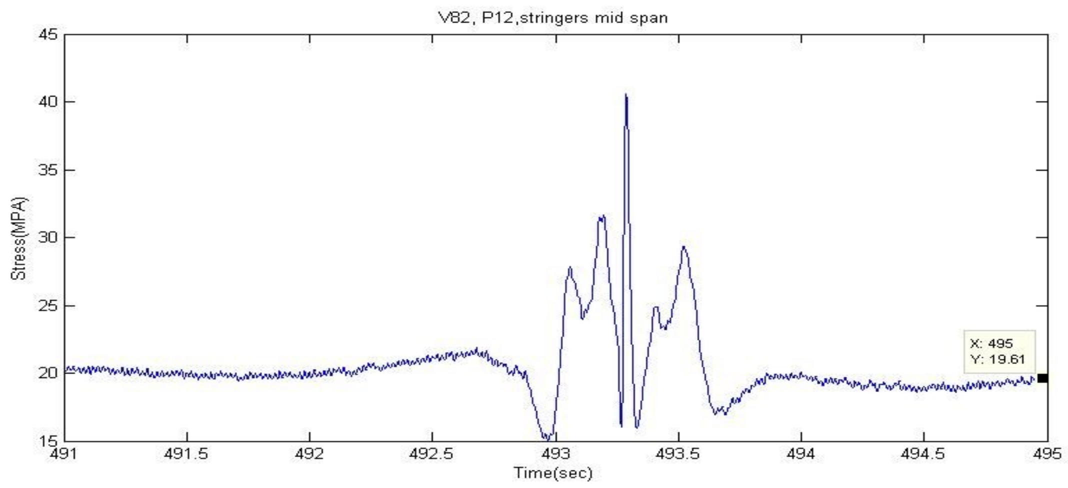
Figure(136) stress history at point 9(82km/hr)



Figure(137) stress history at point 10(82km/hr)

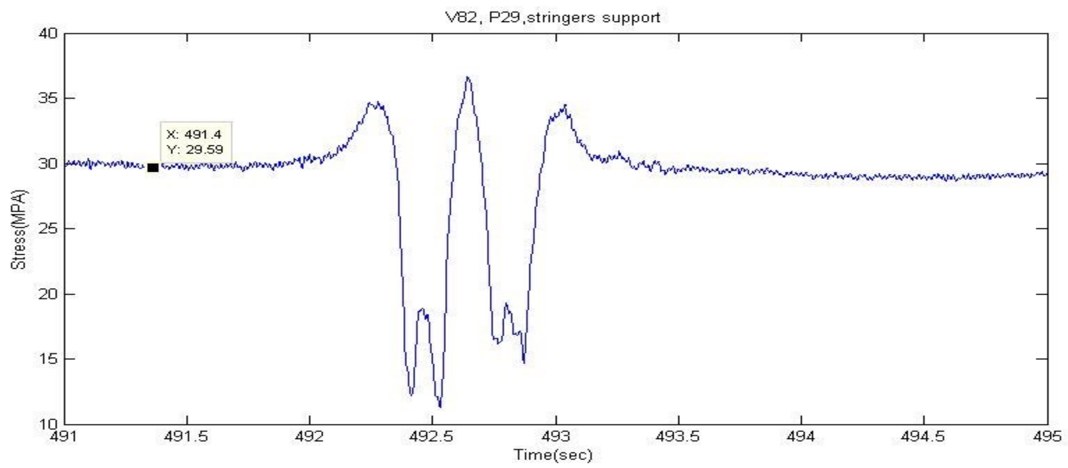


Figure(138) stress history at point 11(82km/hr)

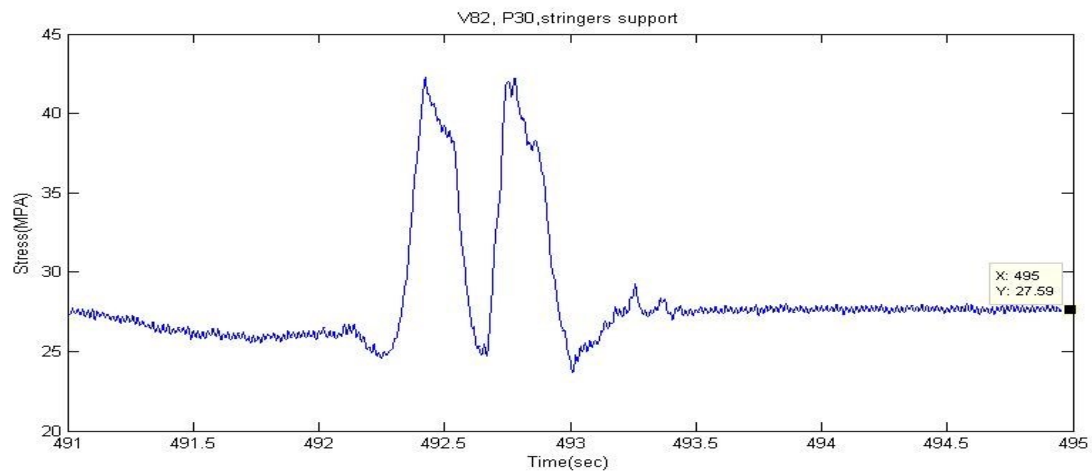


Figure(139) stress history at point 12(82km/hr)

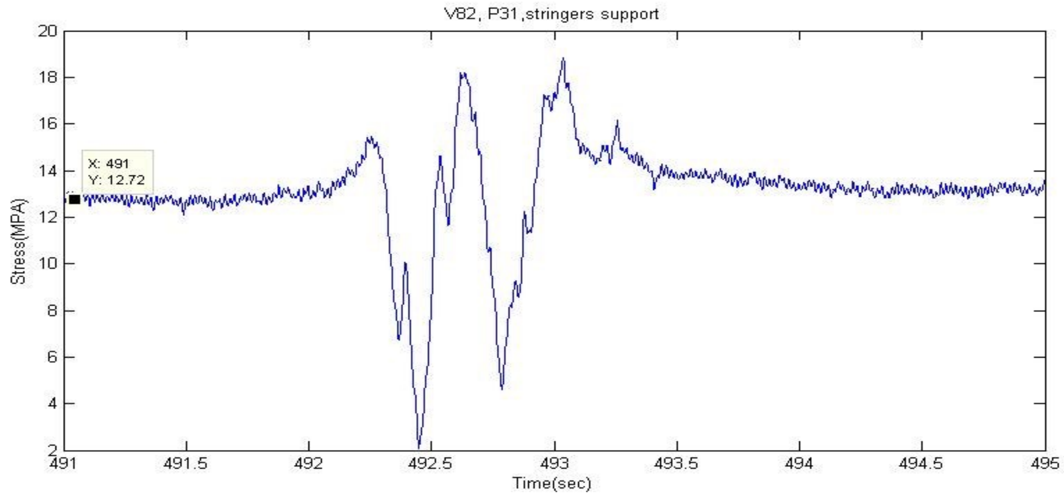
B- Support region



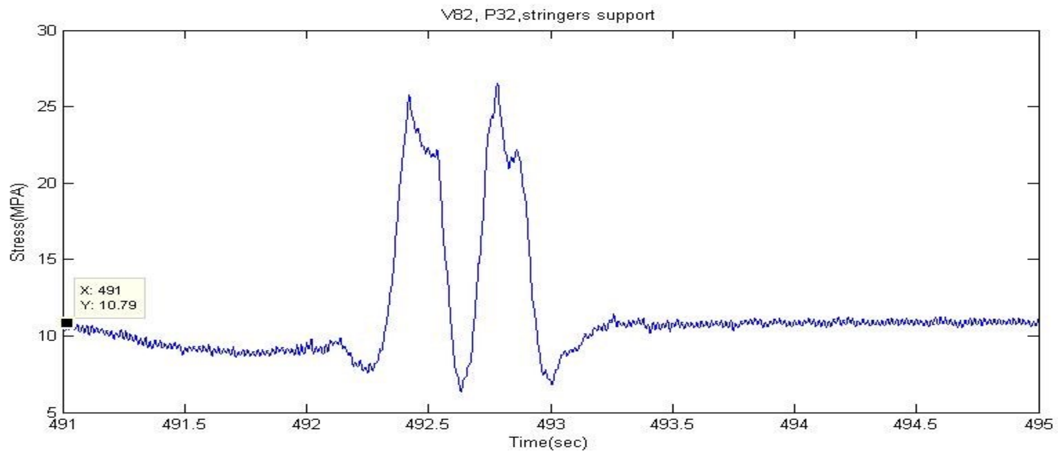
Figure(140) stress history at point 29(82km/hr)



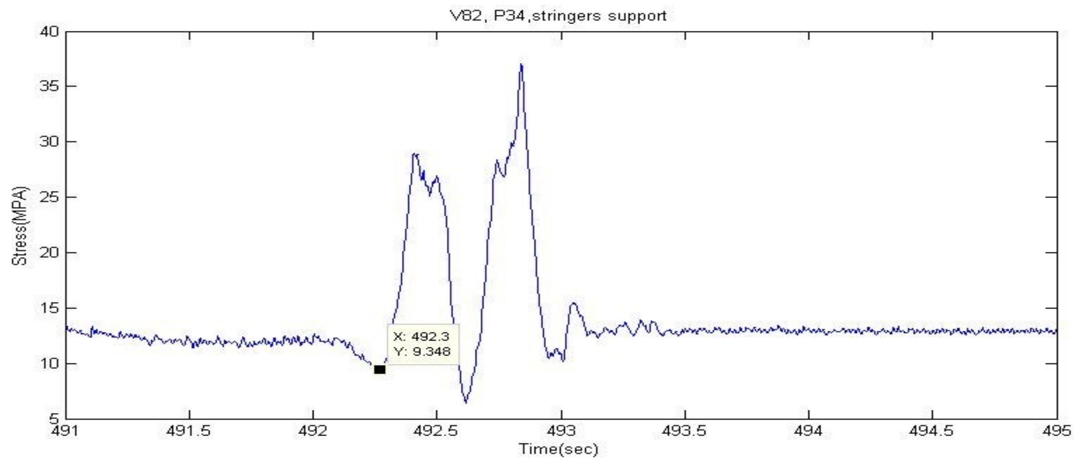
Figure(141)stress history at point 30(82km/hr)



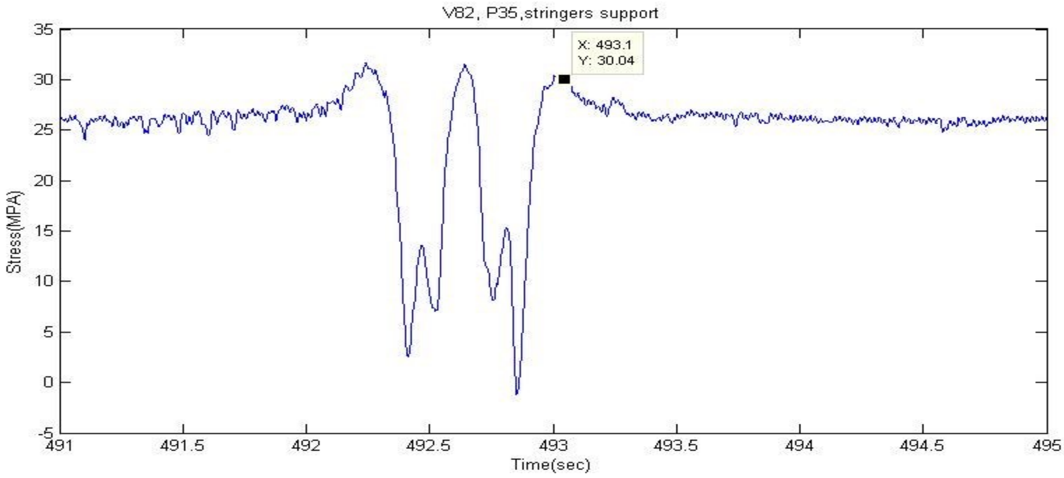
Figure(142)stress history at point 31(82km/hr)



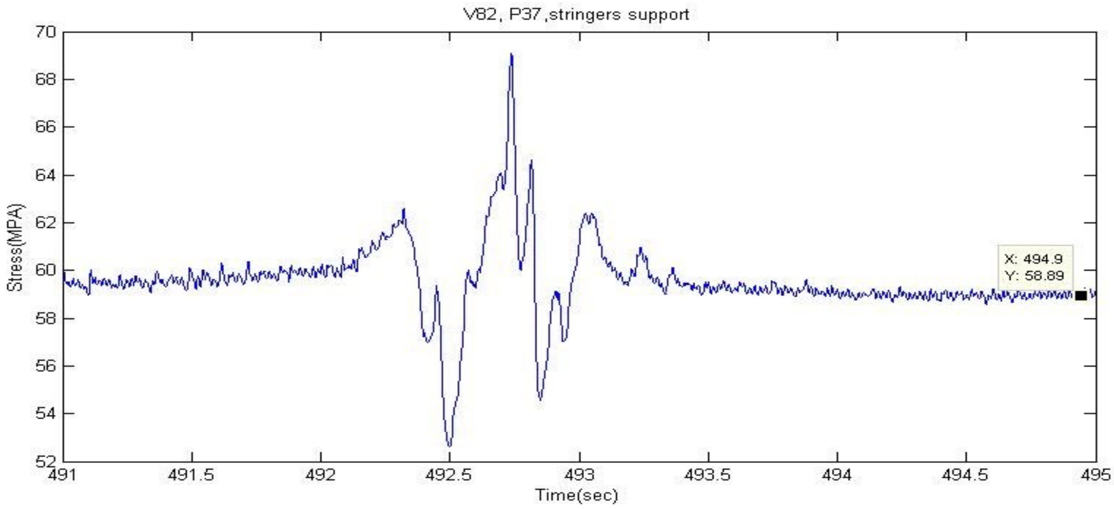
Figure(143)stress history at point 32(82km/hr)



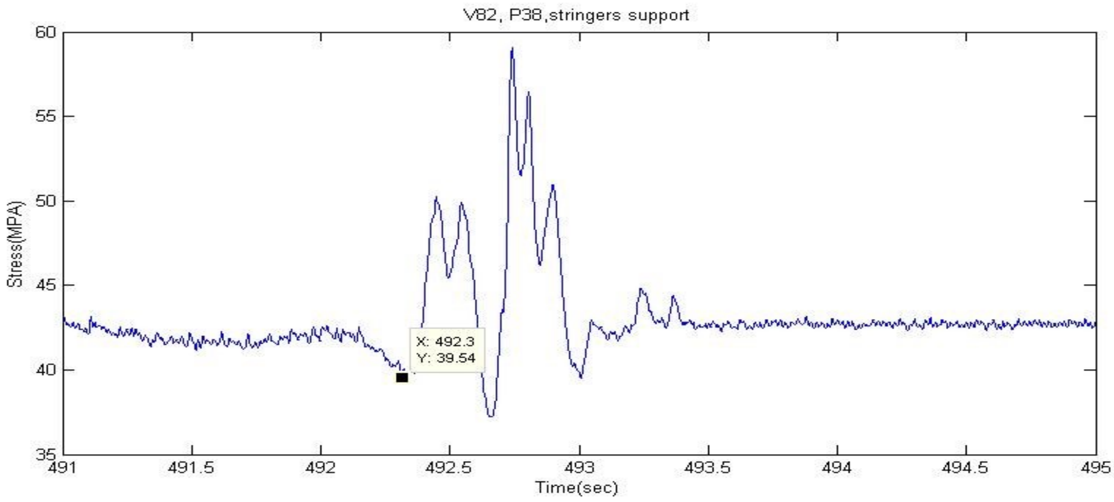
Figure(144)stress history at point 34(82km/hr)



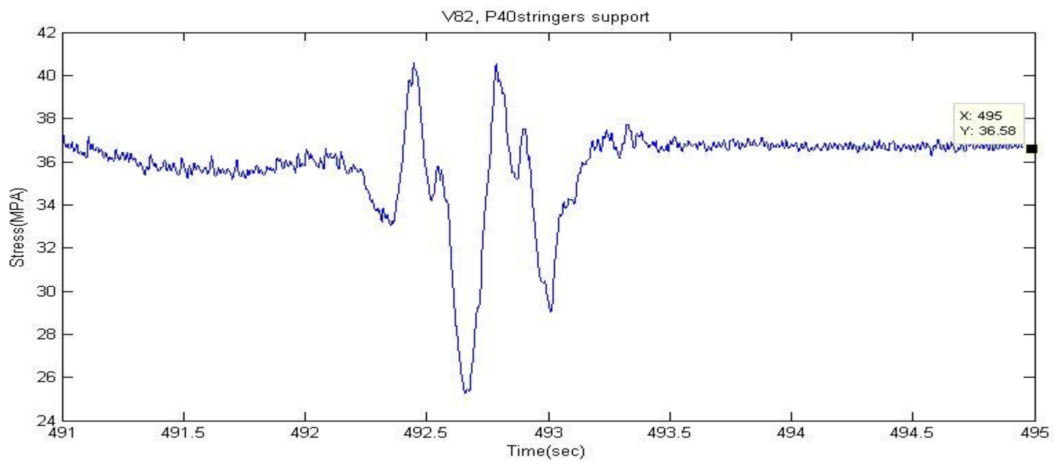
Figure(145)stress history at point 35(82km/hr)



Figure(146)stress history at point 37(82km/hr)

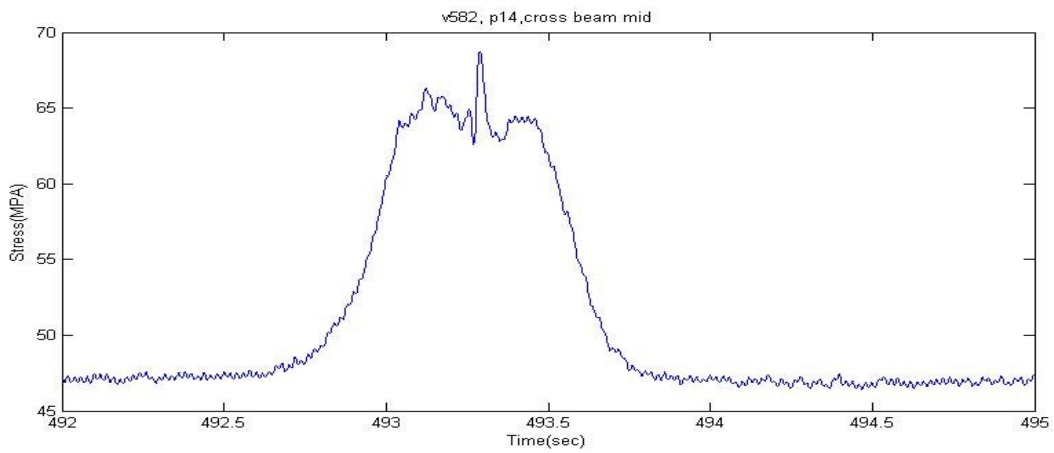


Figure(147)stress history at point 39(82km/hr)

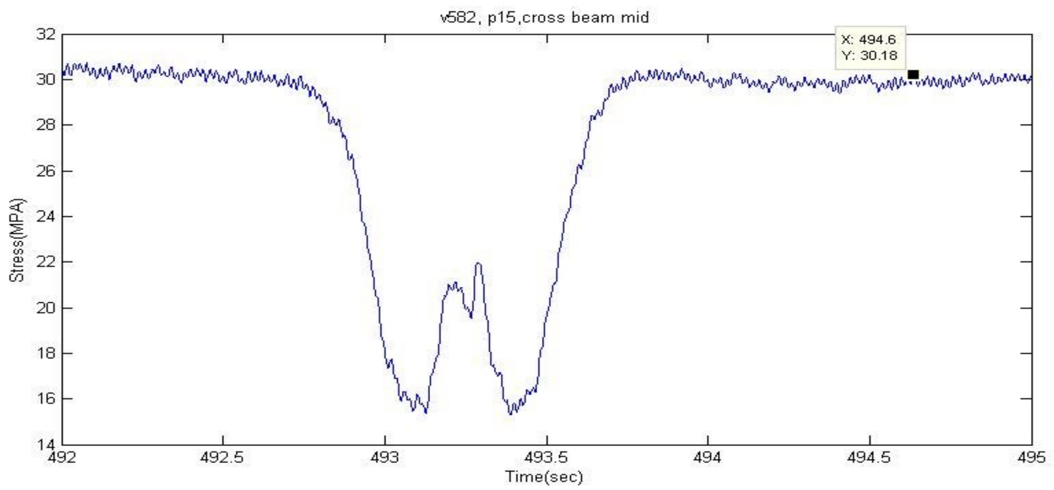


Figure(148)stress history at point 40(82km/hr)

3.3.4.2 Cross beams : A- Mid span region

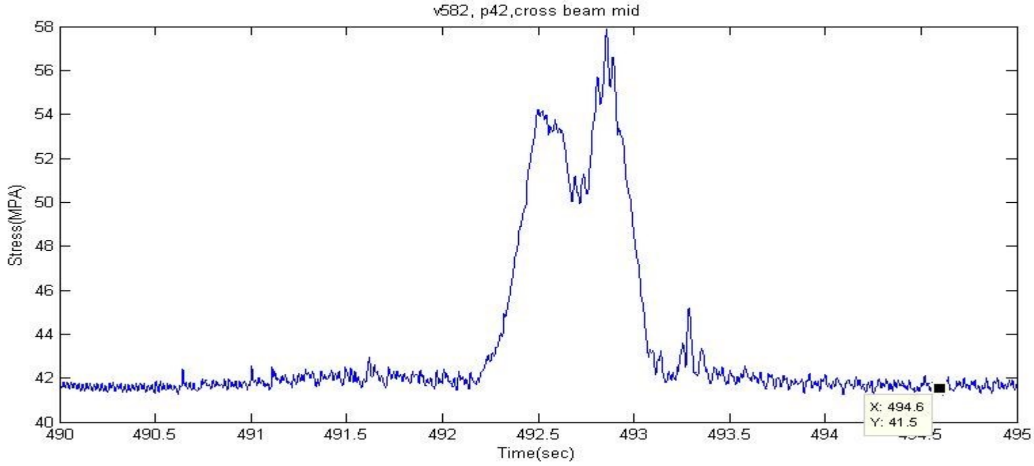


Figure(149)stress history at point 14(82km/hr)

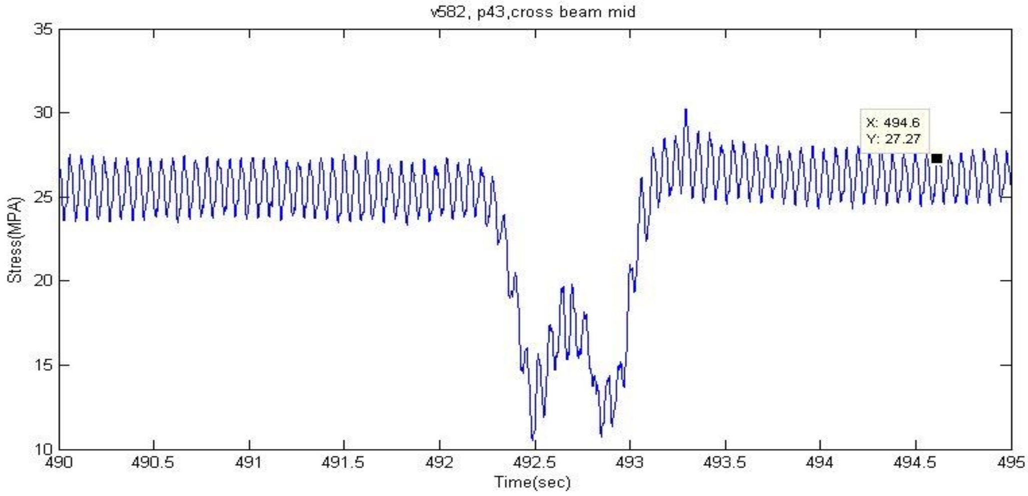


Figure(150)stress history at point 15(82km/hr)

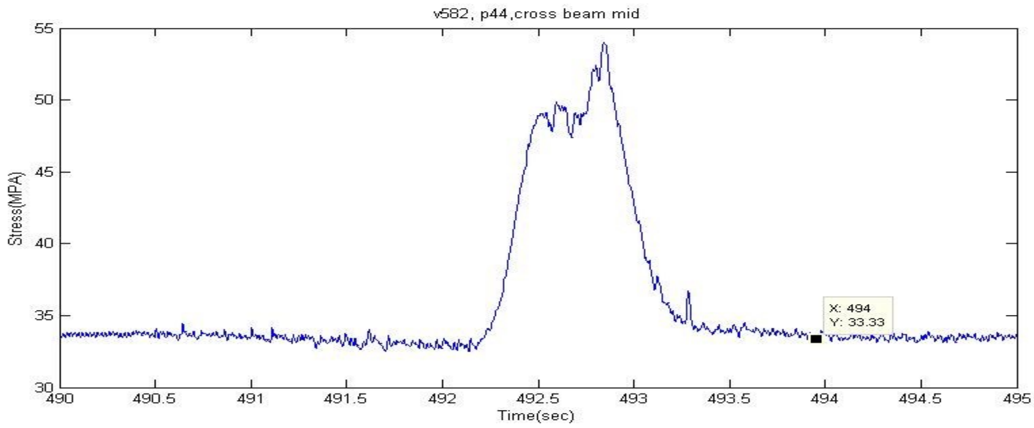
B- Support region



Figure(151)stress history at point 42(82km/hr)

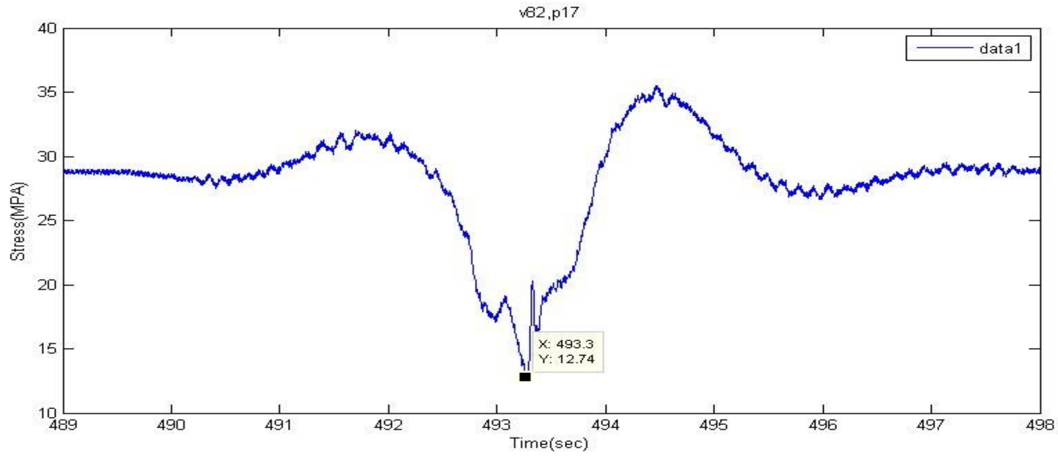


Figure(152)stress history at point 43(82km/hr)

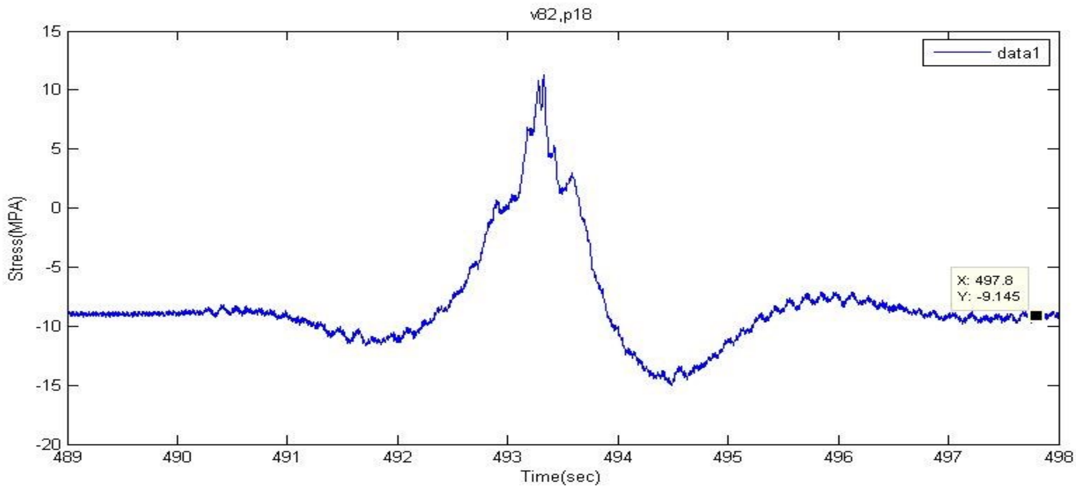


Figure(153)stress history at point 44(82km/hr)

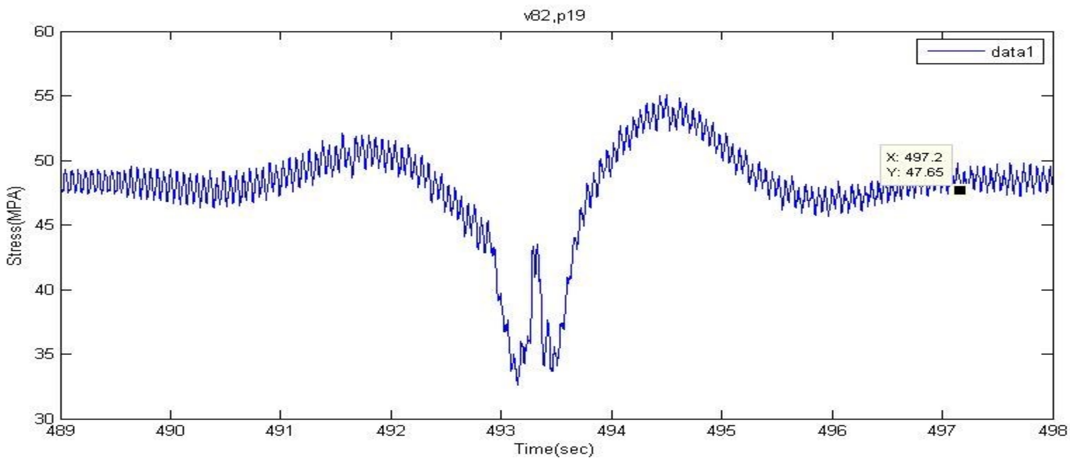
3.3.4.3 Main Girders : A- Mid span region



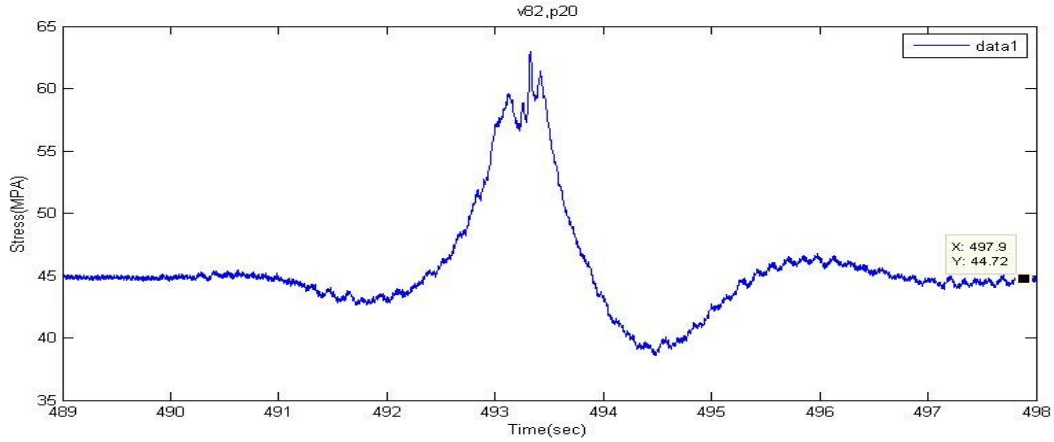
Figure(154)stress history at point 17(82km/hr)



Figure(155)stress history at point 18(82km/hr)

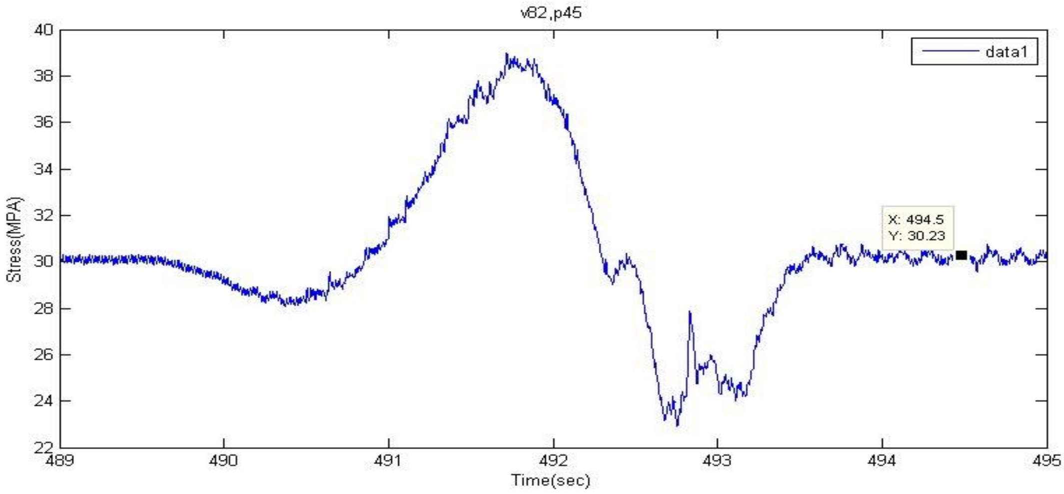


Figure(156)stress history at point 19(82km/hr)

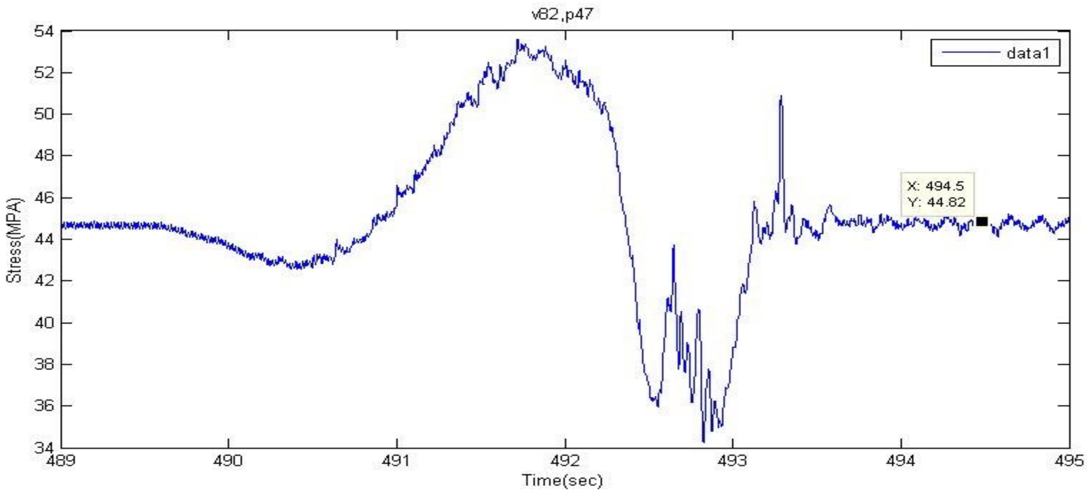


Figure(157)stress history at point 20(82km/hr)

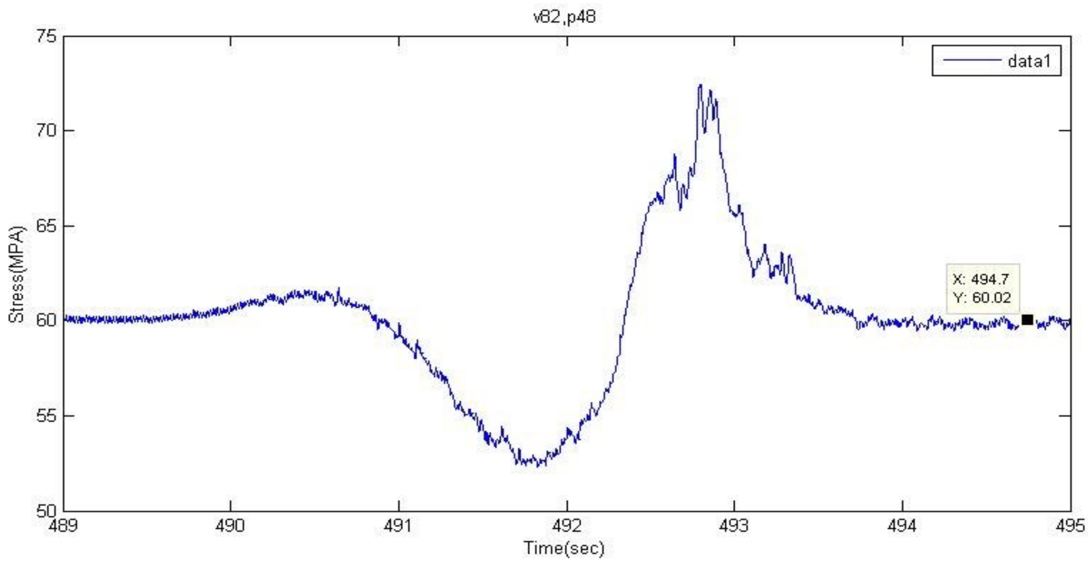
B- Support region



Figure(158)stress history at point 45(82km/hr)



Figure(159)stress history at point 47(82km/hr)



Figure(160)stress history at point 48(82km/hr)

Chapter 4

Results &Discussion

4.1 D.A.F from field measurements

The provided field measurements are used to get the maximum stress response at each recorded point at different velocities (1km/hr(static), 10m/hr, 51km/hr, 52km/hr and 82km/hr). Then, the D.A.F at any point are calculated for all different velocities by using the equation below:

$$D.A.F=\frac{\text{Maximu dynamic stress response}}{\text{Maximun static stress response}}$$

The results are tabulated as follow:

Table 5 D.A.F from field measurements for stringers

points	Velocity (km/hr)	Max stress response (N/m2)	Average static stress	D A F
3	1	72.1997		---------------
3	1	71.3302	73.0049	----------------
3	1	75.4848		----------------
3	10	77.058	--------------	1.056
3	51	73.2336	--------------	1.003
3	52	79.43	---------------	1.088
3	82	76.4832	--------------	1.048
4	1	67.0451		---------------
4	1	67.2223	67.1976	----------------

4	1	67.3253		----------------
4	10	67.0274	--------------	0.997
4	51	67.3157	--------------	1.002
4	52	67.0468	---------------	0.998
4	82	66.9099	--------------	0.996
6	1	33.087		---------------
6	1	33.2351	33.0993	----------------
6	1	32.9759		----------------
6	10	32.6232	--------------	0.986
6	51	34.153	--------------	1.032
6	52	34.3366	---------------	1.037
6	82	33.6603	--------------	1.017
8	1	72.2883		---------------
8	1	72.4606	72.264	----------------
8	1	72.0452		----------------
8	10	72.1901	--------------	0.999
8	51	72.5508	--------------	1.004
8	52	72.8825	---------------	1.009
8	82	72.7682	--------------	1.007
9	1	23.8036		---------------
9	1	25.3672	24.975	----------------
9	1	25.7553		----------------

9	10	27.4396	--------------	1.099
9	51	25.4612	--------------	1.019
9	52	27.0999	---------------	1.085
9	82	31.0097	--------------	1.242
10	1	49.5604		---------------
10	1	51.2802	50.4557	----------------
10	1	50.5266		----------------
10	10	47.2738	--------------	0.937
10	51	51.7923	--------------	1.026
10	52	51.4026	---------------	1.019
10	82	51.9533	--------------	1.03
11	1	41.2174		---------------
11	1	44.4864	43.0328	----------------
11	1	43.3946		----------------
11	10	47.2738	--------------	1.099
11	51	45.0355	--------------	1.047
11	52	44.8632	---------------	1.043
11	82	49.934	--------------	1.16
12	1	34.3559		---------------
12	1	36.7778	36.0644	----------------
12	1	37.0597		----------------
12	10	40.0339	--------------	1.11

12	51	38.145	--------------	1.058
12	52	35.1047	---------------	0.973
12	82	40.8632	--------------	1.133
29	1	37.94		---------------
29	1	37.8216	37.9	----------------
29	1	37.9388		----------------
29	10	37.3624	--------------	0.986
29	51	37.678	--------------	0.994
29	52	38.0274	---------------	1.003
29	82	37.1707	--------------	0.981
30	1	43.73		---------------
30	1	44.0258	43.9648	----------------
30	1	44.1385		----------------
30	10	43.8632	--------------	0.998
30	51	42.9598	--------------	0.977
30	52	42.8599	---------------	0.975
30	82	43.5459	--------------	0.99
31	1	37.94		---------------
31	1	37.8216	37.9	----------------
31	1	37.9388		----------------
31	10	37.3624	--------------	0.986
31	51	37.678	--------------	0.994

31	52	38.0274	---------------	1.003
31	82	37.1707	--------------	0.981
32	1	28.7295		---------------
32	1	28.8036	28.7735	----------------
32	1	28.7875		----------------
32	10	28.8165	--------------	1.001
32	51	26.2142	--------------	0.911
32	52	26.2947	---------------	0.914
32	82	28.5427	--------------	0.992
34	1	33.4396		---------------
34	1	33.364	33.1342	----------------
34	1	32.5991		----------------
34	10	33.3382	--------------	1.006
34	51	34.1643	--------------	1.031
34	52	33.0805	---------------	0.998
34	82	37.0145	--------------	1.117
35	1	35.9131		---------------
35	1	33.8326	33.1342	----------------
35	1	32.5991		----------------
35	10	32.7891	--------------	0.99
35	51	32.6152	--------------	0.984
35	52	37.6651	---------------	1.137

35	82	31.8326	--------------	0.961
37	1	67.174		---------------
37	1	68.4397	67.4628	----------------
37	1	66.7746		----------------
37	10	66.6184	--------------	0.987
37	51	67.7569	--------------	1.004
37	52	66.4123	---------------	0.984
37	82	69.8374	--------------	1.035
38	1	60.5959		---------------
38	1	62.7794	61.1552	----------------
38	1	60.0902		----------------
38	10	59.5363	--------------	0.973
38	51	59.2947	--------------	0.969
38	52	57.4171	---------------	0.939
38	82	59.4284	--------------	0.972
39	1	44.6587		---------------
39	1	45.5363	44.6533	----------------
39	1	43.7649		----------------
39	10	40.6345	--------------	1
39	51	44.5008	--------------	0.997
39	52	42.3849	---------------	0.949
39	82	44.5846	--------------	0.998

40	1	40.9855		---------------
40	1	41.182	41.1208	----------------
40	1	41.1949		----------------
40	10	40.6345	--------------	0.988
40	51	41.2929	--------------	1.004
40	52	42.583	---------------	1.036
40	82	40.7633	--------------	0.991

Table (6) D.A.F from field measurements for cross beams

points	Velocity (km/hr)	Max stress response (N/m2)	Average static stress	D A F
14	1	67.0033		---------------
14	1	66.1063	66.3987	----------------
14	1	65.9356		----------------
14	10	68.7008	--------------	1.035
14	51	66.5653	--------------	1.003
14	52	66.7617	---------------	1.005
14	82	68.6957	--------------	1.035
15	1	30.7649		---------------
15	1	30.8615	30.7456	----------------

15	1	30.7456		----------------
15	10	30.6667	--------------	0.997
15	51	33.0612	--------------	1.073
15	52	30.8873	---------------	1.003
15	82	30.9099	--------------	1.004
42	1	56.9292		---------------
42	1	56.3527	56.8106	----------------
42	1	57.1498		----------------
42	10	57.4429	--------------	1.011
42	51	57.467	--------------	1.011
42	52	60.1015	---------------	1.058
42	82	57.8632	--------------	1.019
43	1	31.905		---------------
43	1	35.6007	33.9598	----------------
43	1	34.3736		----------------
43	10	30.2094	--------------	0.89
43	51	37.0661	--------------	1.091
43	52	33.5411	---------------	1.0915
43	82	30.707	--------------	0.904
44	1	52.7827		---------------
44	1	52.6329	52.7605	----------------
44	1	52.8358		----------------
44	10	53.5041	--------------	1.014

44	51	52.8922	--------------	1.002
44	52	53.9163	---------------	1.022
44	82	58.9839	--------------	1.118

Table (7) D.A.F from field measurements for main girders

points	Velocity (km/hr)	Max stress response (N/m2)	Average static stress	D A F
17	1	32.9936		--------------
17	1	35.0966	34.4461	---------------
17	1	32.248		---------------
17	10	35.1417	--------------	1.020
17	51	35.3269	--------------	1.025
17	52	35.4107	---------------	1.028
17	82	35.4976	--------------	1.029
18	1	11.9855		--------------
18	1	11.0161	10.7423	---------------
18	1	9.2254		---------------
18	10	11.4026	--------------	1.061
18	51	10.0048	--------------	0.93

18	52	9.0741	---------------	0.84
18	82	11.2657	--------------	1.049
19	1	52.583		---------------
19	1	54.029	53.7633	----------------
19	1	54.678		----------------
19	10	54.7714	--------------	1.061
19	51	54.0661	--------------	1.006
19	52	54.8728	---------------	1.021
19	82	55.0612	--------------	1.024
20	1	63.124		---------------
20	1	63.0951	63.0575	----------------
20	1	62.9534		----------------
20	10	63.0178	--------------	0.999
20	51	62.3382	--------------	0.989
20	52	63.6748	---------------	1.01
20	82	63.0017	--------------	0.999
45	1	38.5975		---------------
45	1	38.6347	36.8783	----------------
45	1	33.4026		----------------
45	10	38.4831	--------------	1.044
45	51	39.1128	--------------	1.061
45	52	39.0355	---------------	1.058

45	82	38.9598	--------------	1.056
47	1	53.2393		---------------
47	1	53.401	52.5605	----------------
47	1	51.0412		----------------
47	10	53.7079	--------------	1.022
47	51	53.863	--------------	1.025
47	52	54.2607	---------------	1.032
47	82	55.5165	--------------	1.04

4.2 D.A.F from EUROCODE 1 equations:

The set of equations D1 to D6 and table 1 presented in chapter 2 are used to calculate the D.A.F for different elements at different velocities (10km/hr ,51km/hr , 52km/hr, 82km/hr) but these velocities should change to (m/sec) first to use them in the equations, there value equals (2.7Mile/sec , 14.17 mile/sec, 14.44mile/sec ,22.78 mile/sec) .The obtained D.A.F are presented in table (8) to(10)

Table (8) D.A.F from EUROCODE 1 recommendations for stringers

Velocity (km/hr)	Velocity(m/sec)	D.A.F
10	2.78	1.060
51	14.17	1.10
52	14.44	1.10
82	22.78	1.13

Table (9) D.A.F from EUROCODE 1 recommendations for cross beams

Velocity (km/hr)	Velocity(m/sec)	D.A.F
10	2.78	1.011
51	14.17	1.050
52	14.44	1.051
82	22.78	1.084

Table (10) D.A.F from EUROCODE 1 recommendations for main girders

Velocity (km/hr)	Velocity(m/sec)	D.A.F
10	2.78	1.007
51	14.17	1.039
52	14.44	1.04
82	22.78	1.065

4.3 D.A.F from N.R recommendation

The equation D.6 to D.12 , with tables(2, 3, 4) presented in chapter 2 are used to calculate the D.A.F , the results are shown in table (9) to(11).

Table (9) D.A.F from NR code recommendations for stringers

Velocity (km/hr)	Velocity(Mile/hour)	D.A.F(high frequency)	D.A.F(Low frequency)
10	6.21	1.005	1.009

51	31.69	1.025	1.049
52	32.31	1.025	1.050
82	50.95	1.041	1.083

Table (10) D.A.F from N.Rcode recommendations for cross beams

Velocity (km/hr)	Velocity(Mile/hour)	D.A.F(high frequency)	D.A.F(Low frequency)
10	6.21	1.025	1.025
51	31.69	1.127	1.127
52	32.31	1.129	1.129
82	50.95	1.200	1.200

Table (11) D.A.F from N.Rcode recommendations for main girders

Velocity (km/hr)	Velocity(Mile/hour)	D.A.F(high frequency)	D.A.F(Low frequency)
10	6.21	1.005	1.007
51	31.69	1.017	1.040
52	32.31	1.025	1.041
82	50.95	1.040	1.067

4.4 comparison of D.A.F from all three methods:

For the purpose of comparison of obtained D.A.F , three tables(12 ,13,14) are prepared :

Table (12) D.A.F comparison for stringers

velocity km/hr	D.A.F stringers From data (mid span)	D.A.F stringers From data (support)	D.A.F stringers From EURO code1	D.A.F stringers From NR code(h)	D.A.F stringers From NR code(l)
10	1.035	0.980	1.060	1.005	1.009
51	1.024	0.990	1.100	1.025	1.049
52	1.031	0.990	1.100	1.025	1.050
82	1.079	1.002	1.130	1.041	1.083

Table (13) D.A.F comparison for cross beams

velocity km/hr	D.A.F cross beams From data (mid span)	D.A.F cross beams From data (support)	D.A.F cross beams From EURO code1	D.A.F cross beams From NR code(h)	D.A.F cross beams From NR code(l)
10	1.016	0.970	1.011	1.025	1.025
51	1.038	1.035	1.050	1.127	1.127
52	1.004	1.057	1.051	1.129	1.129
82	1.020	1.014	1.084	1.200	1.200

Table (14) D.A.F comparison for cross beams

velocity km/hr	D.A.F main girders From data (mid span)	D.A.F main girders From data (support)	D.A.F main girders From EURO code1	D.A.F main girders From NR code (h)	D.A.F main girders From NR code(l)
10	1.035	1.026	1.007	1.005	1.007

51	0.990	1.033	1.039	1.017	1.040
52	0.970	1.044	1.040	1.025	1.041
82	1.025	1.033	1.065	1.040	1.067

From the three previous tables, it is observed that there is a difference between the value of D.A.F for different methods. It might be due to the following:

1- The calculation of D.A.F from field measurement is dependent on the stress response of the element at a particular velocity; however, the Eurocode 1 depends on velocity and the length of the member. Never the less, using N.R code depends on the velocity and type of the train (high frequency) and (low frequency).

2- Using field measurements to calculate D.A.F the region of the element is considered (support region) or (mid span region), but the other two methods do not consider that.

Chapter 5

Calculation of Fatigue Damages

One of the advantages of getting D.A.Fs is the calculation of the fatigue damages and remaining fatigue life of the structure. In this dissertation, fatigue damages are calculated by four different methods as clarified below:

1- Considering graphs (1) to graph (150) shown in chapter (3), the stress ranges are calculated for all points using a certain spreadsheet. Then, another spreadsheet is used to calculate the actual fatigue damage using S-N curve equations (N1) and (N2) discussed in chapter 2.

2- The maximum static damage was calculated for all points using the similar procedure of the above method.

3- The fatigue damage, due to field measurements, is calculated by multiplication of static damage with the D.A.F s from tables (6) to (8).

$$\text{Fatigue damage} = \text{D.A.F}_{\text{field measuremets}} \times \text{Static damage}$$

4- The fatigue damage due to EUROCODE 1 recommendations is calculated by multiplication of static damage with the D.A.F s from tables (9)to(11).

$$\text{Fatigue damage} = \text{D.A.F}_{\text{Eurocod 1}} \times \text{Static damage}$$

5- Similarly fatigue damage due to NR CODE 1 recommendations is calculated by multiplication of static damage with the D.A.F s from tables (12)to(14).

$$\text{Fatigue damage} = \text{D.A.F}_{\text{NR code}} \times \text{Static damage}$$

The obtained values are shown in table(15) to table( )

Table (15) Fatigue damage comparison for stringers

region	Velocity &points	Damage from DAF data	Damage from Euro code 1	Damage from NR (h)	Damage from NR(l)	Actual damage
	v10 p3dmg	4.6482E-09	4.76048E-09	4.51347E-09	4.5314E-09	1.47946E-08
mid span	v10 p4 dmg	1.29093E-08	1.32211E-08	1.25351E-08	1.2585E-08	1.09638E-08
	v10p6 dmg	5.8259E-09	5.96662E-09	5.65703E-09	5.6795E-09	4.20391E-09
	v10p8 dmg	2.26128E-08	2.3159E-08	2.19574E-08	2.2045E-08	1.73047E-08
	v10p9dmg	2.98107E-08	3.05308E-08	2.89466E-08	2.9062E-08	4.03281E-08
	v10p10 dmg	2.96675E-09	3.03842E-09	2.88076E-09	2.8922E-09	2.42809E-09
	v10p11dmg	2.06367E-07	2.11352E-07	2.00385E-07	2.0118E-07	2.38763E-07
	v10 p12 dmg	1.36282E-08	1.39574E-08	1.32332E-08	1.3286E-08	2.26616E-08
sum		2.98769E-07	3.05986E-07	2.90109E-07	2.9126E-07	3.51447E-07
avg		3.73461E-08	3.82482E-08	3.62636E-08	3.6408E-08	4.39309E-08
	v10 p29 dmg	1.11286E-10	1.20371E-10	1.14125E-10	1.1458E-10	8.9586E-08
	v10 p30dmg	9.0261E-09	9.76292E-09	9.25635E-09	9.2932E-09	9.39677E-09
	v10 p31dmg	2.87723E-09	3.1121E-09	2.95063E-09	2.9624E-09	1.81057E-08
	v10 p32dmg	1.30437E-08	1.41085E-08	1.33764E-08	1.343E-08	1.41586E-08
	v10 p34dmg	2.6786E-08	2.89726E-08	2.74693E-08	2.7579E-08	2.98832E-08
	v10 p35dmg	8.8968E-08	9.62306E-08	9.12375E-08	9.1601E-08	8.41231E-08
support	v10 p37dmg	1.36689E-09	1.47847E-09	1.40176E-09	1.4073E-09	8.62917E-10
	v10 p38dmg	1.66844E-08	1.80464E-08	1.711E-08	1.7178E-08	9.5383E-09
	v10 p39dmg	6.11185E-09	6.61078E-09	6.26776E-09	6.2927E-09	6.41748E-09
	v10 p40dmg	1.61326E-09	1.74496E-09	1.65442E-09	1.661E-09	1.52346E-09
sum		1.66589E-07	1.80188E-07	1.70838E-07	1.7152E-07	2.63596E-07
avg		1.66589E-08	1.80188E-08	1.70838E-08	1.7152E-08	2.63596E-08

region	Velocity &points	Damage from DAF data	Damage from Euro code 1	Damage from NR (h)	Damage from NR(l)	Actual damage
	v51 p3 dmg=	4.5988E-09	4.94012E-09	4.60329E-09	4.71107E-09	4.95275E-09
mid span	v51 p4 dmg=	1.27721E-08	1.372E-08	1.27846E-08	1.30839E-08	1.10088E-08
	v51p6dmg=	5.76398E-09	6.19178E-09	5.76961E-09	5.9047E-09	7.20826E-09
	v51 p8 dmg	2.23725E-08	2.4033E-08	2.23944E-08	2.29187E-08	2.54381E-08
	v51 p9 dmg	2.94939E-08	3.16829E-08	2.95227E-08	3.0214E-08	1.09526E-11
	v51p10 dmg	2.93522E-09	3.15307E-09	2.93809E-09	3.00688E-09	3.04094E-09
	v51 p11dmg	2.04174E-07	2.19327E-07	2.04373E-07	2.09159E-07	2.06119E-07
	v51 p12 dmg	1.34834E-08	1.44841E-08	1.34965E-08	1.38125E-08	1.35202E-08
sum		2.95594E-07	3.17532E-07	2.95882E-07	3.0281E-07	2.71299E-07
avg		3.69492E-08	3.96915E-08	3.69853E-08	3.78513E-08	3.39124E-08
	v51 p29 dmg	1.12422E-10	1.24913E-10	1.16396E-10	1.19122E-10	4.04191E-08
support	v51 p30 dmg	9.1182E-09	1.01313E-08	7.55144E-09	9.66161E-09	1.74362E-08
	v51 p31dmg	2.90659E-09	3.22954E-09	3.22954E-09	3.07981E-09	3.03049E-09
	v51 p32 dmg	1.31768E-08	1.46409E-08	1.36426E-08	1.39621E-08	9.49021E-09
	v51 p34 dmg	2.70593E-08	3.00659E-08	2.80159E-08	2.86719E-08	3.08056E-08
	v51 p35 dmg	8.98758E-08	9.9862E-08	9.30532E-08	9.5232E-08	7.97207E-08
	v51 p37 dmg	1.38084E-09	1.53426E-09	1.42965E-09	1.46313E-09	8.99259E-10
	v51 p38 dmg	1.68546E-08	1.87274E-08	1.74505E-08	1.78591E-08	9.5383E-09
	v51 p39 dmg	1.69159E-08	1.87955E-08	1.7514E-08	1.7924E-08	6.41748E-09
	v51 p40 dmg	1.62973E-09	1.81081E-09	1.68734E-09	1.72685E-09	1.8409E-09
sum		1.7903E-07	1.98922E-07	1.83691E-07	1.897E-07	1.99598E-07
avg		1.7903E-08	1.98922E-08	1.83691E-08	1.897E-08	1.99598E-08

Table (16) continue

region	Velocity &points	Damage from DAF data	Damage from Euro code 1	Damage from NR (h)	Damage from NR(l)	Actual damage
mid span	v52 p3 dmg	4.63E-09	4.94012E-09	4.60329E-09	4.71557E-09	2.0314E-08
	v52 p4dmg	1.286E-08	1.372E-08	1.27846E-08	1.30964E-08	1.0044E-08
	v52 p6 dmg	5.803E-09	6.19178E-09	5.76961E-09	5.91033E-09	7.2297E-09
	v52 p8 dmg	2.253E-08	2.4033E-08	2.23944E-08	2.29406E-08	2.7685E-08
	v52 p9 dmg	2.97E-08	3.16829E-08	2.95227E-08	3.02428E-08	3.3773E-08
	v52 p10 dmg	2.955E-09	3.15307E-09	2.93809E-09	3.00975E-09	3.0381E-09
	v52 p11 dmg	2.056E-07	2.19327E-07	2.04373E-07	2.09358E-07	3.748E-09
	v52 p12 dmg	1.358E-08	1.44841E-08	1.34965E-08	1.38257E-08	6.7105E-09
sum		2.976E-07	3.17532E-07	2.95882E-07	3.03099E-07	1.1254E-07
avg		3.72E-08	3.96915E-08	3.69853E-08	3.78874E-08	1.4068E-08
	v52 p29 dmg	1.124E-10	1.24913E-10	1.16396E-10	1.19235E-10	4.2234E-08
support	v52 p30 dmg	9.118E-09	1.01313E-08	9.44056E-09	9.67082E-09	1.203E-08
	v52 p31 dmg	2.907E-09	3.22954E-09	3.00934E-09	3.08274E-09	2.7896E-09
	v52 p32 dmg	1.318E-08	1.46409E-08	1.36426E-08	1.39754E-08	9.4675E-09
	v52 p34 dmg	2.706E-08	3.00659E-08	2.80159E-08	2.86992E-08	2.6023E-08
	v52 p35 dmg	8.988E-08	9.9862E-08	9.30532E-08	9.53228E-08	8.4695E-08
	v52 p37 dmg	1.381E-09	1.53426E-09	1.42965E-09	1.46452E-09	4.8398E-10
	v52 p38 dmg	1.685E-08	1.87274E-08	1.74505E-08	1.78761E-08	5.9833E-09
	v52 p39 dmg	1.692E-08	1.87955E-08	1.7514E-08	1.79411E-08	2.9801E-09
	v52 p40 dmg	1.63E-09	1.81081E-09	1.68734E-09	1.7285E-09	2.1464E-09
sum		1.79E-07	1.98922E-07	1.8536E-07	1.89881E-07	1.8883E-07
avg		1.79E-08	1.98922E-08	1.8536E-08	1.89881E-08	1.8883E-08

Table (16) continue

region	Velocity &points	Damage from DAF data	Damage from Euro code 1	Damage from NR (h)	Damage from NR(l)	Actual damage
	v51 p3 dmg=	4.5988E-09	4.94012E-09	4.60329E-09	4.71107E-09	4.95275E-09
mid span	v51 p4 dmg=	1.27721E-08	1.372E-08	1.27846E-08	1.30839E-08	1.10088E-08
	v51p6dmg=	5.76398E-09	6.19178E-09	5.76961E-09	5.9047E-09	7.20826E-09
	v51 p8 dmg	2.23725E-08	2.4033E-08	2.23944E-08	2.29187E-08	2.54381E-08
	v51 p9 dmg	2.94939E-08	3.16829E-08	2.95227E-08	3.0214E-08	1.09526E-11
	v51p10 dmg	2.93522E-09	3.15307E-09	2.93809E-09	3.00688E-09	3.04094E-09
	v51 p11dmg	2.04174E-07	2.19327E-07	2.04373E-07	2.09159E-07	2.06119E-07
	v51 p12 dmg	1.34834E-08	1.44841E-08	1.34965E-08	1.38125E-08	1.35202E-08
sum		2.95594E-07	3.17532E-07	2.95882E-07	3.0281E-07	2.71299E-07
avg		3.69492E-08	3.96915E-08	3.69853E-08	3.78513E-08	3.39124E-08
	v51 p29 dmg	1.12422E-10	1.24913E-10	1.16396E-10	1.19122E-10	4.04191E-08
support	v51 p30 dmg	9.1182E-09	1.01313E-08	7.55144E-09	9.66161E-09	1.74362E-08
	v51 p31dmg	2.90659E-09	3.22954E-09	3.22954E-09	3.07981E-09	3.03049E-09
	v51 p32 dmg	1.31768E-08	1.46409E-08	1.36426E-08	1.39621E-08	9.49021E-09
	v51 p34 dmg	2.70593E-08	3.00659E-08	2.80159E-08	2.86719E-08	3.08056E-08
	v51 p35 dmg	8.98758E-08	9.9862E-08	9.30532E-08	9.5232E-08	7.97207E-08
	v51 p37 dmg	1.38084E-09	1.53426E-09	1.42965E-09	1.46313E-09	8.99259E-10
	v51 p38 dmg	1.68546E-08	1.87274E-08	1.74505E-08	1.78591E-08	9.5383E-09
	v51 p39 dmg	1.69159E-08	1.87955E-08	1.7514E-08	1.7924E-08	6.41748E-09
	v51 p40 dmg	1.62973E-09	1.81081E-09	1.68734E-09	1.72685E-09	1.8409E-09
sum		1.7903E-07	1.98922E-07	1.83691E-07	1.897E-07	1.99598E-07
avg		1.7903E-08	1.98922E-08	1.83691E-08	1.897E-08	1.99598E-08

Table (16) Fatigue damage comparison for Cross beams

region	Velocity &points	Damage from DAF data	Damage from Euro code 1	Damage from NR (h)	Damage from NR(l)	Actual damage
	v10 p14 dmg	4.60581E-09	4.58314E-09	4.64661E-09	4.6466E-09	8.38828E-09
mid span	v10 p15 dmg	1.38555E-09	1.37874E-09	1.39783E-09	1.3978E-09	1.29531E-09
sum		5.99136E-09	5.96188E-09	6.04444E-09	6.0444E-09	9.68358E-09
avg		2.99568E-09	2.98094E-09	3.02222E-09	3.0222E-09	4.84179E-09
	v10 p42 dmg	1.2262E-09	1.27802E-09	1.29572E-09	1.2957E-09	1.94852E-09
support	v10 p43dmg	1.76489E-08	1.83948E-08	1.86496E-08	1.865E-08	8.49431E-09
	v10 p44dmg	5.49404E-09	5.72627E-09	5.80556E-09	5.8056E-09	6.66281E-09
sum		3.93475E-08	4.03038E-08	4.08619E-08	4.0862E-08	1.71056E-08
avg		9.83688E-09	1.0076E-08	1.02155E-08	5.8374E-09	5.70188E-09

region	Velocity &points	Damage from DAF data	Damage from Euro code 1	Damage from NR (h)	Damage from NR(l)	Actual damage
	v51 p14 dmg=	4.70554E-09	4.75994E-09	5.109E-09	5.109E-09	4.98236E-09
mid span	v51 p15 dmg=	1.41556E-09	1.43192E-09	1.53693E-09	1.53693E-09	1.21572E-09
sum		6.1211E-09	6.19186E-09	6.64593E-09	6.64593E-09	6.19808E-09
avg		3.06055E-09	3.09593E-09	3.32297E-09	3.32297E-09	3.09904E-09
	v51 p42 dmg	1.30836E-09	1.32732E-09	1.42466E-09	1.42466E-09	2.0027E-09
support	v51 p43 dmg	1.88315E-08	1.91044E-08	2.05054E-08	2.05054E-08	8.09817E-09
	v51 p44 dmg	5.8622E-09	5.94716E-09	6.38329E-09	6.38329E-09	5.97189E-09
sum		2.60021E-08	2.63789E-08	2.83134E-08	2.83134E-08	1.60728E-08
avg		8.66736E-09	8.79297E-09	9.43779E-09	9.43779E-09	5.35759E-09

Table (16) continue

region	Velocity &points	Damage from DAF data	Damage from Euro code 1	Damage from NR (h)	Damage from NR(l)	Actual damage
	v52 p14 dmg	4.551E-09	4.76448E-09	5.11807E-09	5.11807E-09	5.6649E-09
mid span	v15 p15dmg	1.369E-09	1.43329E-09	1.53966E-09	1.53966E-09	1.1047E-09
sum		5.921E-09	6.19776E-09	6.65773E-09	6.65773E-09	6.7696E-09
avg		2.96E-09	3.09888E-09	3.32886E-09	3.32886E-09	3.3848E-09
	v52 p42 dmg	1.336E-09	1.32859E-09	1.42719E-09	1.42719E-09	3.6438E-09
support	v52 p43 dmg	1.923E-08	1.91226E-08	2.05418E-08	2.05418E-08	8.2272E-09
	v52p44 dmg	5.987E-09	5.95282E-09	6.39461E-09	6.39461E-09	7.8135E-09
sum		2.655E-08	2.6404E-08	2.83636E-08	2.83636E-08	1.9684E-08
avg		8.852E-09	8.80134E-09	9.45454E-09	9.45454E-09	6.5615E-09

region	Velocity &points	Damage from DAF data	Damage from Euro code 1	Damage from NR (h)	Damage from NR(l)	Actual damage
	v82 p14 dmg	4.62394E-09	4.91407E-09	5.43993E-09	5.43993E-09	9.48378E-09
mid span	v82 p15dmg	1.39101E-09	1.47829E-09	1.63648E-09	1.63648E-09	1.39557E-09
sum		6.01495E-09	6.39236E-09	7.07642E-09	7.07642E-09	1.08794E-08
avg		3.00748E-09	3.19618E-09	3.53821E-09	3.53821E-09	5.43968E-09
	v82 p42 dmg	1.28185E-09	1.3703E-09	1.51694E-09	1.51694E-09	2.31075E-09
support	v82 p43dmg	1.84494E-08	1.9723E-08	2.18336E-08	2.18336E-08	2.93892E-09
	v82 p44dmg	5.74326E-09	6.13974E-09	6.79675E-09	6.79675E-09	7.39493E-09
sum		2.54745E-08	2.72331E-08	3.01473E-08	3.01473E-08	1.26446E-08
avg		8.49151E-09	9.0777E-09	1.00491E-08	1.00491E-08	4.21486E-09

region	Velocity &points	Damage from DAF data	Damage from Euro code 1	Damage from NR (h)	Damage from NR(l)	Actual damage
	v10 p17 dmg	9.55036E-09	9.29199E-09	9.27354E-09	9.292E-09	9.29197E-09
mid span	v10 p18 dmg	2.047E-08	1.99162E-08	1.98766E-08	1.9916E-08	2.06515E-08
	v10p19 dmg	4.38132E-08	4.26279E-08	4.25432E-08	4.2628E-08	9.00174E-09
	v10 p20 dmg	1.50801E-08	1.46722E-08	1.4643E-08	1.4672E-08	1.2635E-08
sum		8.89136E-08	8.65082E-08	8.63364E-08	8.6508E-08	5.15802E-08
avg		2.22284E-08	2.16271E-08	2.15841E-08	2.1627E-08	1.2895E-08
	v10 p45 dmg	1.79386E-09	1.76064E-09	1.75715E-09	1.7606E-09	1.89295E-09
support	v10 p47dmg	5.41608E-09	5.31578E-09	5.30523E-09	5.3158E-09	4.98482E-09
	v10 p48dmg	5.49473E-09	5.39297E-09	5.38226E-09	5.393E-09	7.06492E-09
sum		1.27047E-08	1.24694E-08	1.24446E-08	1.2469E-08	1.39427E-08
avg		4.23489E-09	4.15647E-09	4.14821E-09	4.1565E-09	4.64756E-09

Table (16) Fatigue damage comparison for Main Girders

region	Velocity &points	Damage from DAF data	Damage from Euro code 1	Damage from NR (h)	Damage from NR(l)	Actual damage
	v51 p17 dmg=	9.13513E-09	9.58727E-09	9.38426E-09	9.5965E-09	9.77258E-09
mid span	v51 p18 dmg=	1.958E-08	2.05491E-08	2.0114E-08	2.05689E-08	1.74362E-08
	v51p19dmg=	4.19082E-08	4.39825E-08	4.30512E-08	4.40248E-08	1.14312E-08
	v51 p20 dmg	1.44245E-08	1.51384E-08	1.48179E-08	1.5153E-08	2.68261E-12
sum		8.50478E-08	8.92572E-08	8.73673E-08	8.93431E-08	3.86427E-08
avg		2.1262E-08	2.23143E-08	2.18418E-08	2.23358E-08	9.66068E-09

	v51 p45 dmg	1.8061E-09	1.81659E-09	1.77813E-09	1.81834E-09	1.99676E-09
support	v51 p47 dmg	1.08258E-08	5.48471E-09	5.35339E-09	5.48998E-09	4.98431E-09
	v51 p48 dmg	5.53221E-09	5.56435E-09	5.56435E-09	5.5697E-09	1.89295E-09
sum		1.81641E-08	1.28656E-08	1.26959E-08	1.2878E-08	8.87402E-09
avg		6.05471E-09	4.28855E-09	4.23196E-09	4.29268E-09	2.95801E-09

region	Velocity &points	Damage from DAF data	Damage from Euro code 1	Damage from NR (h)	Damage from NR(l)	Actual damage
	v52 p17 dmg	8.951E-09	9.5965E-09	9.45808E-09	9.60572E-09	1.0249E-08
mid span	v52 p18dmg	1.918E-08	2.05689E-08	2.02722E-08	2.05886E-08	1.4542E-08
	v52 p19 dmg	4.106E-08	4.40248E-08	4.33899E-08	4.40672E-08	7.03E-09
	v52 p20 dmg	1.413E-08	1.5153E-08	1.49344E-08	1.51675E-08	9.8132E-09
sum		8.333E-08	8.93431E-08	8.80545E-08	8.94291E-08	4.1634E-08
avg		2.083E-08	2.23358E-08	2.20136E-08	2.23573E-08	1.0409E-08
	v52 p45 dmg	1.825E-09	1.81834E-09	1.79212E-09	1.82009E-09	1.9968E-09
support	v52 p47 dmg	5.511E-09	5.48998E-09	5.4108E-09	5.49526E-09	4.262E-09
	v52 p48 dmg	5.591E-09	5.5697E-09	5.48937E-09	5.57506E-09	1.1307E-08
		1.293E-08	1.2878E-08	1.26923E-08	1.28904E-08	1.7565E-08
avg		4.309E-09	4.29268E-09	4.23076E-09	4.2968E-09	5.8551E-09

	v82 p17 dmg	**9.45808E-09**	**9.82718E-09**	**9.5965E-09**	**9.84563E-09**	**1.13029E-08**
mid span	v82 p18 dmg	2.02722E-08	2.10633E-08	2.05689E-08	2.11029E-08	2.23654E-08
	v82 p19 dmg	4.33899E-08	4.50831E-08	4.40248E-08	4.51678E-08	9.6888E-09

	v82 p20 dmg	1.49344E-08	1.55174E-08	1.5153E-08	1.55464E-08	1.56103E-08
sum		8.80545E-08	9.1491E-08	8.93431E-08	9.16626E-08	5.89675E-08
avg		2.20136E-08	2.28727E-08	2.23358E-08	2.29157E-08	1.47419E-08
	v82 p45 dmg	1.8061E-09	1.86205E-09	1.81834E-09	1.86555E-09	2.19884E-09
support	v82 p47dmg	5.45303E-09	5.62196E-09	5.48998E-09	5.63251E-09	5.01605E-09
	v82 p48dmg	5.53221E-09	5.70359E-09	5.5697E-09	5.7143E-09	5.85321E-09
sum		1.27914E-08	1.31876E-08	1.2878E-08	1.32124E-08	1.30681E-08
avg		4.26378E-09	4.39587E-09	4.29268E-09	4.40412E-09	4.35603E-09

Chapter 6

Conclusion:

This assignment presents a study of the structural behaviour of Soderstrom bridge in Stockholm which locates in central Sweden. Three different methods are used to calculate the dynamic amplification factors (D.A.F) for the bridge elements (Stringers, main girders, and cross beams). The field measurements are carried out by using RC6 Swedish locomotive train with different velocities (1 Km/hr, 51km/hr, 52 km/hr and 82 km/hr). The monitoring and recording data are carried out for a period of 43 days.

The obtained data is used as a source to calculate the D.A.F, plotting stress history curves to, finally, get the more realistic damage. Also, two codes of practice (EURO CODE1, NR CODE) are used for the same purposes. The overall study can be concluded in the followings:

1- Using field measurements for calculating of both D.A.F and fatigue damage may be closer to the actual damage of the bridge because it depends basically on the stress ranges of the structural elements as a response to a particular velocity.

2- Using the other two options are dependent on the length of the elements and velocity of the train.

3- Fatigue damages obtained from D.A.F concept sometimes might be overestimated, for example, the average fatigue damage at mid span for 82km/hr in table 17 from actual stress response is 1.47×10^{8}. However, obtained fatigue damage from D.A.F of field measurements is 2.2 x 10^8, from EUROCODE 1 is 2.28 x 10^8, from N. R code (high frequency) and (low frequency) are 2.23 x 10^8 and 2.29 x 10^8 respectively.

4- According to the aforementioned point, it can be observed that using D.A.F for calculating fatigue damage might be a non-economic method; however, it is the most conservative way for fatigue damage estimation. Furthermore, using D.A.F from field measurements is the closest to the actual damage compared the other two methods.

5- In most cases, for this bridge the damages at mid span is greater than damage at supports.

It might be better to calculate the actual fatigue damage rather than the other alternative methods to estimate the remaining fatigue life of the bridges. However, the data used in this study is from RC6 locomotive train for a period of 43 days - not from a real traffic - the obtained D.A.F for the real traffic may be different.

It is suggested that further study can be demonstrated by monitoring and recording the response of other bridges under the real traffics for a period of one year to get the most realistic fatigue damages in order to provide the most economic assessment practice.

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