Chapter 7

EXPERIMENTAL RESULTS AND INTERPRETATION

The experimental results were obtained with procedures discussed in the previous chapter. The test methods used in this study were also verified and validated with a test experiment, comparing the different results of an experimental test, with the analytical and finite element analysis (FEA) methods. Well calibrated test setups and the suitable measuring equipment produced the experimental data. After the establishment of reliable data generation, several runs of each of the different experiments were carried out. Only the final results and average values of the tests are presented and discussed. The complete data sets are presented in Appendix D.

7.1 FINITE ELEMENT ANALYSIS VERIFICATION

An experiment was carried out to verify the generated results. The experiment was done in conjunction with analytical calculations and SolidWorks® FEA simulations to determine the stress in a sample material piece. The SolidWorks® FEA offers two techniques to solve such a problem, namely beam analysis and solid body analysis. Strain gauges were applied to the test sample piece. The material used for this experiment was the same material that the chassis frame was manufactured of. The test sample piece was subjected to known loadings in order to calculate the stresses involved (Figure 7-1). The test sample piece was fitted with four identical strain gauges. The results of the four stress calculation methods were assessed to study and verify the methods used in this study.

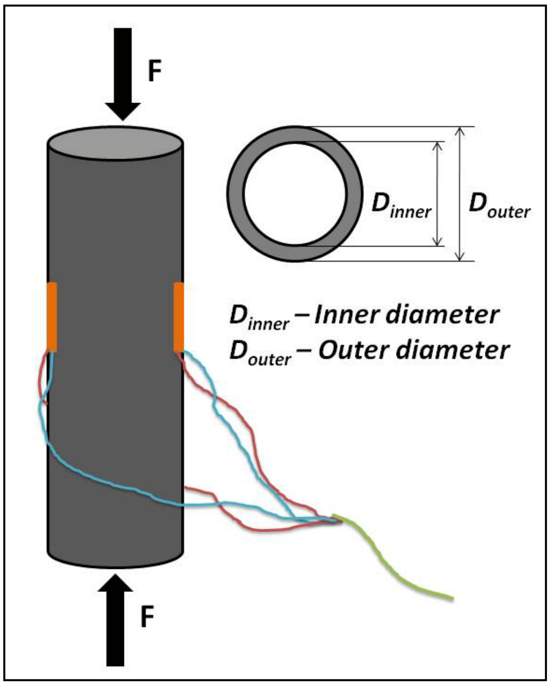

Figure 7-1: Illustration of the sample experiment (left) and a photo of the sample piece (right)

The experimental stress was determined by the same technique discussed in Section 6.3.3. Four strain gauge readings were used to determine the stress experimentally. The experiment consisted of the same procedures discussed in Section 6.2.3.

Determining the stresses analytically, (7.1) was used

$$\sigma = \frac{F}{A_{pipe}} \tag{7.1}$$

F represents the input force and A_{pipe} represents the area. In this experiment, it is the area of the pipe wall is calculated as

$$\begin{aligned} A_{pipe} &= A_{outer} - A_{inner} \\ A_{pipe} &= \frac{\pi}{4} D_{outer} - \frac{\pi}{4} D_{inner} \\ A_{pipe} &= \frac{\pi}{4}\left[D_{outer} - D_{inner}\right] \end{aligned} \tag{7.2}$$

Substituting (7.2) into (7.1) yields the formula to calculate the stress in a tubular member analytically, given in (7.3)

$$\sigma = \frac{F}{\frac{\pi}{4}\left[D_{outer} - D_{inner}\right]} \tag{7.3}$$

The SolidWorks® FEA simulation method consists of two techniques. The first technique is the beam analysis solution. The beam analysis solution uses one-dimensional or a beam mesh type. It is normally used for structural applications such as chassis frames. The second technique is the solid body solution. It uses a three dimensional tetrahedral mesh type and requires extensive computing power. The solid body solution technique is mostly used in any solid body model applications.

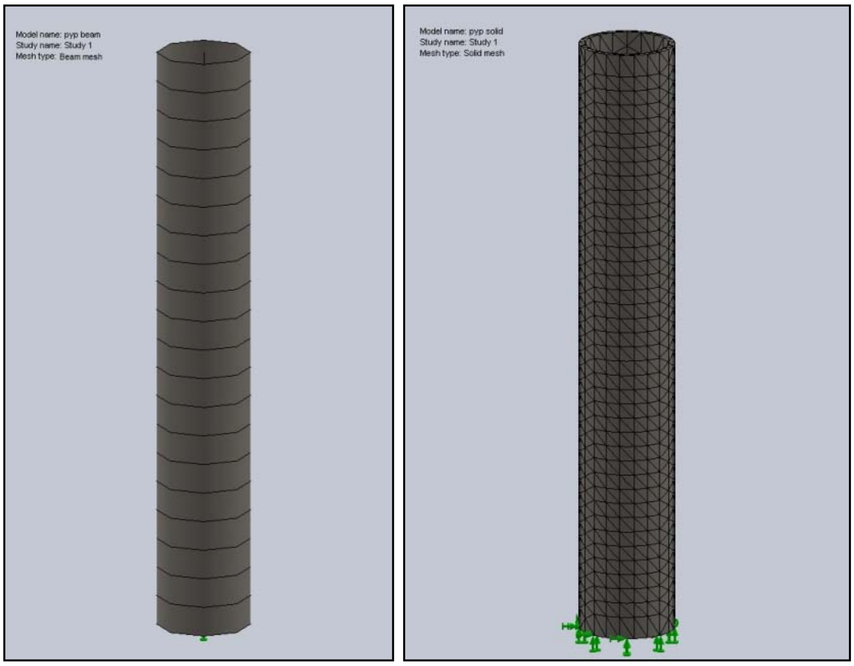

Figure 7-2: SolidWorks® FEA mesh type illustrations; beam mesh (left) and solid mesh (right)

Table 7-1: Data of the different stress calculation methods

Force, F [N]	Stress, σ [MPa]			
	Analytical	Experimental	Beam Analysis	Solid Analysis
100	0.89	0.20	0.84	0.87
150	1.33	0.79	1.25	1.31
200	1.78	1.58	1.67	1.75
250	2.22	1.77	2.09	2.19
300	2.66	2.17	2.51	2.62
350	3.11	2.56	2.93	2.62
400	3.55	2.96	3.34	3.50
450	4.00	3.35	3.76	3.94
500	4.44	3.55	4.18	4.37
750	6.66	5.91	6.27	6.56
1000	8.88	8.08	8.36	8.74
1500	13.32	12.22	12.54	13.12
2000	17.76	16.75	16.72	17.49
3000	26.64	25.42	25.08	26.24

Table 7-1 shows the calculated stress data of the different calculation methods. Figure 7-3 illustrates the relation between the four methods for determining the test piece's stresses. The results verify that the FEA simulation software of SolidWorks® is reliable and correlate with the experimental and analytical solutions. It applies to both the simulation techniques offered by the SolidWorks® FEA software. The simulation results are thus verified and supported by both the analytical and experimental values.

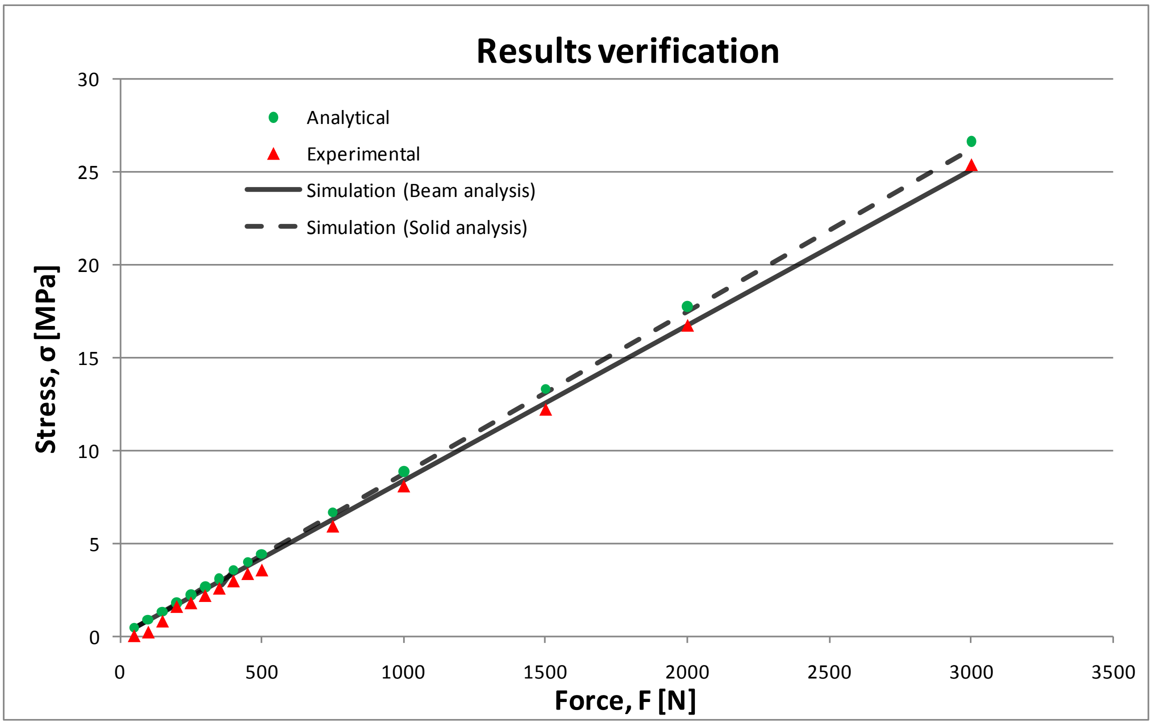

Figure 7-3: Graph illustrating the relation between the four calculation methods

A trend line is statistically calculated for the four sets of results generated. The percentage errors of the trend line equation gradients are also calculated to evaluate the deviation and difference of the results in terms of the experimental results. The statistical applications of the experimental results will be discussed in the next section.

Table 7-2: Assessed of Results

Results Verification	Trend Line Equation	Percentage Error
Experimental	y = 8298x	-
Analytical	y = 8878x	6.53 %
Beam analysis	y = 8359x	0.73 %
Solid analysis	y = 8736x	5.01 %

Table 7-2 shows the relationship of the data generated by the results verification experiment. The graphs in Figure 7-3 indicate that the analytical and the SolidWorks® solid solution corresponds while the experimental results and the SolidWorks® beam solution coincide closely. The phenomenon is confirmed by the percentage errors in Table 7-2. The results verification experiments indicate that the error made by the different solution techniques is less than 6.6 %.

7.2 ASSESSMENT AND INTERPRETATION OF RESULTS

The results generated with the simulation studies were compared to the data produced by the experimental procedures. The results are described with each set's coefficient of determination (R^2-value) and a fitted linear trend line. The R^2-value is an indication of the data points' linear characteristics while the trend line equation indicates the slope of the data sets (Devore & Farnum, 2005). The percentage error was also calculated for each case in (7.4) as

$$\%_{Error} = \left(\frac{Simulation - Experiment}{Simulation} \right) \times 100 \qquad (7.4)$$

A percentage error below 5% was accepted for this study.

7.2.1 CHASSIS WEIGHT RESULTS

The weight of the frame was experimentally determined together with its longitudinal centre of gravity. The centre of gravity was calculated using the techniques described in Chapter 7.

Table 7-3: Chassis weight results

Chassis Weight	Value [kg]	Percentage Error
Simulation	33.075	0.88 %
Experimental	33.37	
Chassis Longitudinal C.O.G	**Value [mm]**	**Percentage Error**
Simulation	1269.50	1.09 %
Experimental	1255.67	

Table 7-3 presents the experimental and simulation results of the chassis frame's weight and the longitudinal centre of gravity. The percentage errors found are very low taking into account the simplicity of the experimental setup, hence indicating the accuracy of the simulation model.

7.2.2 CHASSIS TORSIONAL STIFFNESS

Figure 7-4 shows the graph of the angular deflection, comparing simulated and experimental results. The angular deflections are used to calculate the torsional stiffness of the chassis frame. The graph also indicates that both the simulation and experimental results have linear characteristics. The linearity of the results indicates that the chassis frame has a linear behaviour with regard to torsional input and the accompanying angular displacement. The fitted trend line of the simulation results had a R^2-value exceptionally close to 1, confirming the linear properties of its torsional stiffness. The R^2-values and linearity was replicated by the experimental results.

With convincing linear characteristics, the gradient of the results indicated another characteristic of the chassis frame. The trend line defined by the results had a specific gradient which defined the torsional stiffness of the chassis frame. Equation (6.6) defines the torsional stiffness.

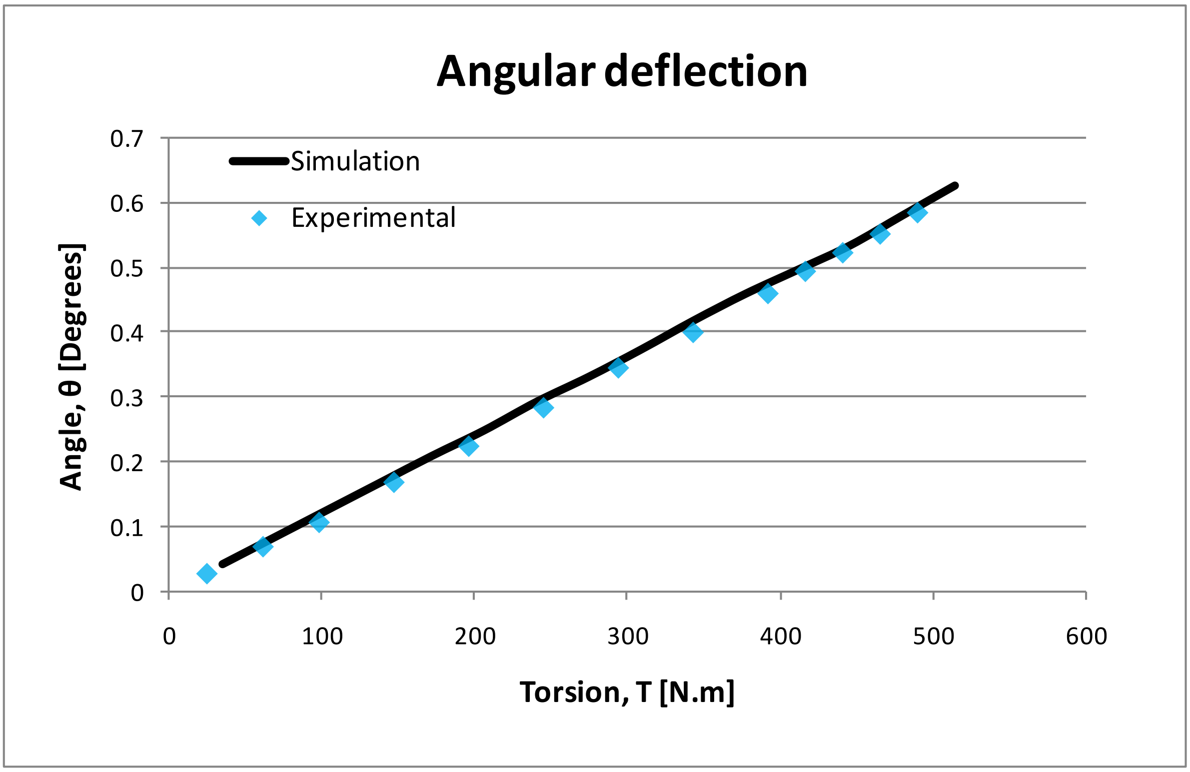

Figure 7-4: Graph illustrating the relationship between the experimental and simulation angular deflection

Table 7-4: Torsional stiffness result properties

	R^2 - Value	Trend Line Equation	Percentage Error
Simulation	0.99985	$y = 0.00121x$	3.31 %
Experimental	0.99907	$y = 0.00117x$	

Table 7-4 presents the statistical properties of the simulation and experimental results. It also provides the gradients of the fitted trend lines to calculate the chassis frame's torsional stiffness. The graph's slope is defined in (7.5)

$$m = \frac{\Delta\theta}{\Delta T} \tag{7.5}$$

The relationship indicates that the inverted values of the trend line gradients produced in the Table 4-3 will provide the chassis frame's torsional stiffness. Thus,

$$K_{Torsional} = \frac{1}{m} = \frac{\Delta T}{\Delta \theta} \tag{7.6}$$

$$K_{Torsional\_Simulation} = 826.45 \frac{N.m}{Degree}$$

The simulated torsional stiffness was calculated as 826.45 N.m/degree, whereas the experimental torsional stiffness was calculated as 854.7 N.m/degree.

The percentage error of the simulation and experimental results was calculated in order to establish the differences in the results obtained. The value defined the total percentage difference between the results and was given as 3.31 %.

7.2.3 CHASSIS STRESSES RESULTS

The chassis stress results are presented according to the five different locations tested. Only the stress results of the different cluster locations are presented and not the accompanying strain results. The different strain gauge cluster locations on the chassis frame are shown in Figure 4-4. The experimental stress results were calculated by the technique discussed in Chapter 6.

Figure 7-5 and Figure 7-6 show the simulation and experimental results of the STR_{MAX} stresses at the respective locations on the same axes.

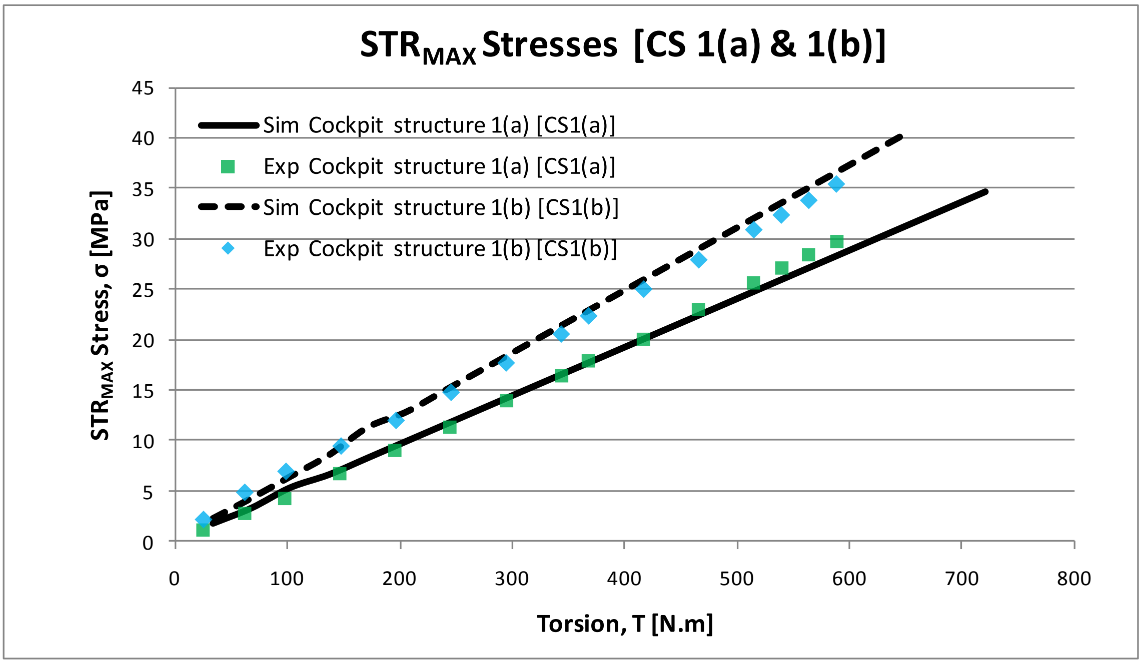

Figure 7-5: Graph illustrating experimental and simulated STR_{MAX} stress at CS 1(a) and CS 1(b)

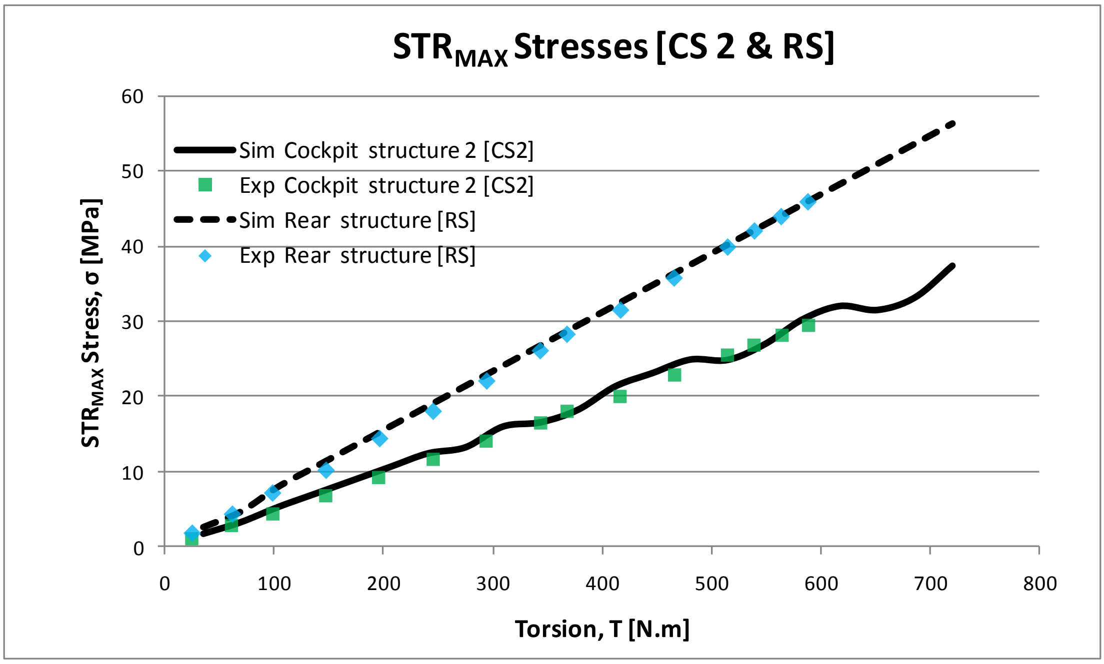

Figure 7-6: Graph illustrating experimental and simulated STR_{MAX} stress at CP 2 and RS

Table 7-5: STR_{MAX} stress results properties

Location	Result	R^2 - Value	Trend Line Equation	Percentage Error
CS 1(a)	Simulation	0.9999	$y = 48156x$	2.38 %
	Experimental	0.9971	$y = 49304x$	
CS 1(b)	Simulation	0.9999	$y = 62238x$	3.31 %
	Experimental	0.998	$y = 60178x$	
CS 2	Simulation	0.995	$y = 50179x$	1.96 %
	Experimental	0.9984	$y = 49195x$	
RS	Simulation	0.9999	$y = 78040x$	1.73 %
	Experimental	0.9984	$y = 76689x$	

Table 7-5 includes the result properties of the four accompanying stresses in the structural members. All the stress results on the four stress locations on the chassis frame presented had linear characteristics. The results produced R^2-values above 0.99 for every member studied for both the experimental and simulation cases. The high R^2-values indicate that stresses in each of the studied member locations increased linearly with an increase in torsional input.

The gradients of the results describe the rate of change of stress against torsion. The different test locations on the structural members produced different gradients, depending on the structural member's load characteristics which were dependent on the entire chassis frame. The gradients produced by the results of CS 1(a) and CS 2 are fairly similar due to the locations of clusters CS 1(a) and CS 2 located symmetrically opposite each other on the chassis. They are not identical due to the phenomenon that one of the members will experience tension stress while the other one compressive stress. There are also structural geometric differences in the chassis frame.

The percentage errors for each case is calculated and presented in Table 7-5. The highest percentage error is calculated as 3.31%, which is lower than the acceptable value of 5%.

Front structure strain cluster results

The fifth and final strain gauge cluster results are discussed separately as it differs from the previous four sets of results. The simulation predicted higher stress values than the experimental data. But except for the different values, both the simulation and experimental results produced values with linear behaviour, with R^2-values above 0.999. Both the linear and R^2-value characteristics show that the principle and tested techniques are correct, though the experimental stress values are lower than the results produced by the simulation.

The differences found in the results imply that the physical chassis frame experienced less stress than that predicted by the results produced by the SolidWorks® simulation. The experimental results produced the expected linear characteristics expected from non-faulty measurement procedures. Figure 7-7 shows the STR_{MAX} stresses of the simulation and experimental results produced by the front structure strain cluster.

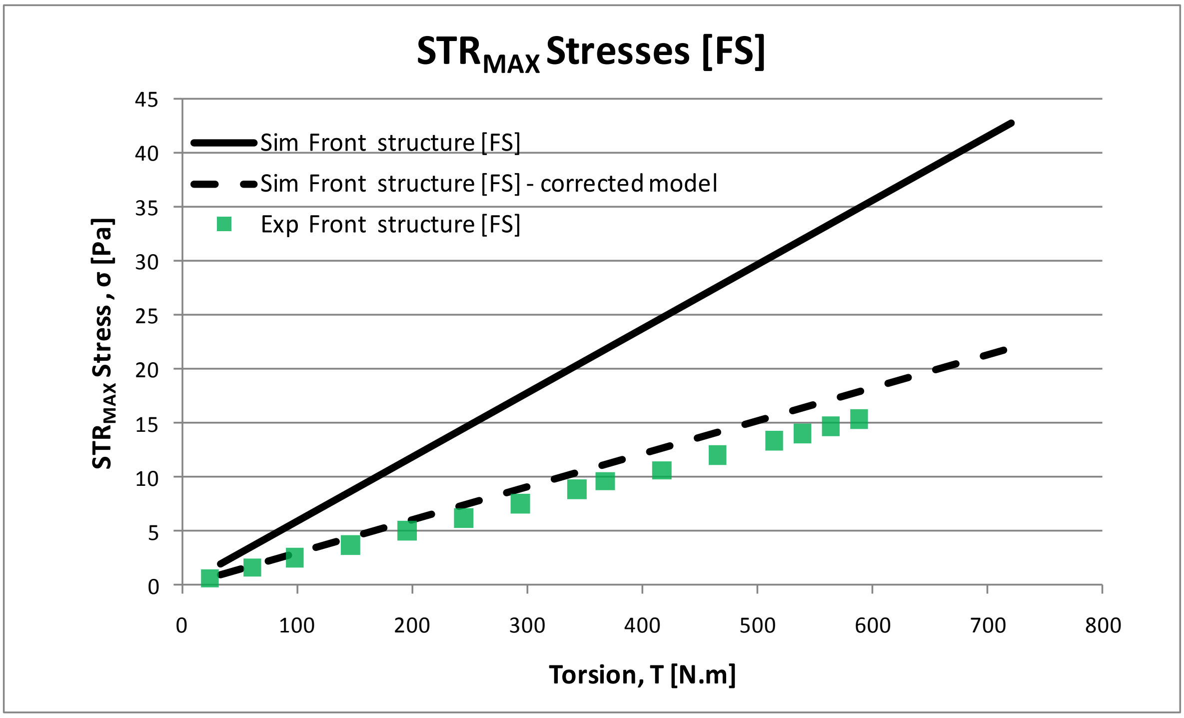

Figure 7-7: Graph illustrating the STR_{MAX} stresses at location FS1

Close investigations revealed that the physical frame and simulation model had small differences with regard to the structural member lengths, triangulation orientation and chassis symmetry. The differences had arisen during the construction process. Corrections were made to the simulation model to match the physical frame as closely as possible. The simulations tests were repeated and produced a second set of results. Figure 7-7 also shows the results of the corrected FEA model.

Table 7-6: STR_{MAX} stress results properties for the FS1 cluster

Location	Result	R^2 - Value	Trend Line Equation	Percentage Error
FS (Original)	Simulation	1	$y = 59330x$	56.25 %
	Experimental	0.9996	$y = 25956x$	
FS (Corrected)	Simulation	1	$y = 30471x$	17.39 %
	Experimental	0.9996	$y = 25956x$	

Table 7-6 presents the statistical characteristics of the original and corrected results, together with the experimental results. The corrected results were more accurate than the experimental data. The simulation results still produced values higher that the experimental results, but only with a percentage error of 17% compared to the original 56%. The fifth cluster's results were more complex because of its location on the model and the factors influencing it. The differences of the FS cluster results can be ascribed to measurement faults due to the manufacturing process of the chassis frame.

7.3 RESULTS DISCUSSION

The simulation and experimental data provided valuable results. The results also provided insights into the designed chassis frame regarding its specifications and characteristics.

Both the experimental and simulation results confirmed the behaviour expected from the loading conditions and material properties. Except for the fifth and final stress result, all the experimental data produced excellent results regarding its statistical properties and percentage errors. The validity of the design study could be proven and the chassis frame's characteristics could be quantified.

7.3.1 WEIGHT

The percentage error between the physical model and the SolidWorks® FEA software calculations for the chassis weight is 0.88%. The study validated that the FEA software's weight calculation capabilities are reliable. The designed value of 33.075 kg for the chosen chassis concept was thus accurate and valid.

The percentage error between the physical model and the SolidWorks® FEA software calculation for the longitudinal centre of gravity is 1.09%. The study validated that the FEA software calculated the longitudinal centre of gravity reliably. The result therefore concluded that the two remaining coordinates would also be reliable. The chassis frame's designed centre of gravity coordinates (x=0mm; y=273.3mm; z=1269.5mm) were thus accurate and valid.

7.3.2 TORSIONAL STIFFNESS

The percentage error for the chassis frame's torsional stiffness between the physical model and the SolidWorks® FEA software was 3.31%. The study validated that the FEA software's displacement results are reliable for calculating the chassis frame's torsional stiffness. Two angular displacements were measured to improve accuracy. The relative torsional stiffness between the two angular displacements was calculated as 826.45 N.m/deg. The results concluded that the designed chassis torsional stiffness of 473 N.m/deg is accurate and valid.

7.3.3 STRESSES

The percentage error between the physical model and the SolidWorks® FEA software ranged from 1.96% to 3.31%.for the chassis frame stresses. The study validated that the FEA software's stress calculation capabilities and results are reliable. The fifth and last strain gauge cluster's poor result correlation was due to measuring faults discussed in the previous section. The study concluded that the safety factor of the FEA software was accurate and valid and that failure would occur with a torsional moment higher than 833 N.m.

7.4 CONCLUSION

The results of the simulation and experimental results were discussed in this chapter. An experiment was also performed to verify the results produced by the FEA. The results of the three design characteristics for a race car chassis (weight, torsional stiffness and strength) were assessed and compared. All the obtained results were satisfactory in terms of behaviour and expectations.

The next chapter will present the study's conclusions. It will discuss the outcome and findings of the study, together with recommendations for future studies.