Bolt Selection Analysis

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INTRODUCTION

The purpose of the bolt selection analysis is to ensure that the bolts for each bumper for both clients will not fail during impact or under a high load from the winch. The bumper being made for our client Carson Pete will have the highest loads and will require the most analysis. Carson's vehicle is a 2008 Chevy Silverado 3500 which has a Gross Vehicle Weight Rating (gvwr) of 9200 lbs [1]. The second vehicle we will analyze is David Bui's 2011 Jeep Liberty (kk). The Jeep Liberty has half the weight of the Silverado and its gvwr is 5600lbs [2]. These values provide useful information to compare our forces too. The forces that the bolts in our capstone will be experiencing are 1.5 times that [6]. This number will account for small impacts the vehicle will experience as well as the force needed to get the vehicle unstuck with the winch. This analysis will provide the team with a cost-effective solution by determining the minimum size required for the bolts, as well as the hardness grade of the bolt. The bolts used in both vehicles are metric bolts and this analysis will find the results of only metric bolts.

There are multiple factors to consider when finding the maximum force on the bolts. The team will first consider the factory bolt sizes and find if those sizes are appropriate for the new, heavier, bumper. Next, a force analysis will be calculated to find the maximum forces each bolt will experience. Then, a factor of safety analysis will be performed for the bolts to ensure that they will not have to be replaced after m impacts/loads. Finally, a bill of materials will be created after the correct bolts have been selected. This will give the team a better understanding of the required materials and the corresponding prices.

EXPERIMENTAL METHODS AND VERIFICATION

For this analysis, a testing procedure has been made to ensure that numbers found online will be accurate to use. The testing procedure will analyze the bolts from the manufacturer that the team will be using to mount the bumper and winch. The process for this is to use a hydraulic press and two metal plates to create a single shear on the bolt. Since the bolts are mostly holding a plate to either the vehicle or the winch, all bolts as of now will be experiencing a single shear. Appendix A at the bottom of this report will show the shear plates (A-1), the hydraulic press (A-2), the measurement gauge (A-3), the sheared bolts (A-4), and a photo of the bolt shearing during the test (A-5).

To start the experiment the measurement gauge used on the hydraulic press was calibrated by a load cell. The bolts were inserted into the shears and each bolt was tightened to the same torque spec. After this the shearing device and bolt were placed into a hydraulic press. Then, the force was applied to the bolt through the hydraulic press. The bolt eventually sheared under a certain amount of force. From this, we can calculate the shear stress on the bolt and the maximum force applied to the bolt. To ensure that the data is accurate the bolts were compared against data available online. The results from the test show that the average data from the bolts is accurate compared to the online table values. The data in Table 1: Online values for bolt shear stressTable 1: Online values for bolt shear stress is the bolt material properties found online and we will use these values for the remainder of our calculations. We are using these values compared to the tested values because only 5 bolts were sheared during the test and the averages were taken from that data. However, the data online takes a much larger sample size and is evaluated with less uncertainty. Furthermore, the data online and the test data are similar in magnitude. Table 2 shows the data that was calculated from the test. This data was collected using the above method and shows that some bolts have a higher force than the expected values while some have a lower. Overall, when comparing the two data sets there is a 20% difference in the values of each test. In other words, the values are all within 100lbs of the expected values.

Table 1: Online values for bolt shear stress [3]

Thread d *(mm)*	Pitch P *(mm)*	Nominal Stress Area $A_{s,nom}$ *(mm^2)*	Property Class								
			4.6	4.8	5.6	5.8	6.8	8.8	9.8	10.9	12.9
			Minimum Ultimate Tensile Load - $F_{m,min}$ *(N) (kg,lbf)*								
M3	0.50	5.03	2010 205, 452	2110 215, 474	2510 256, 564	2620 267, 589	3020 308, 679	4020 410, 904	4530 462, 1018	5230 533, 1176	6140 626, 1380
M3.5	0.60	6.78	2710 276, 609	2850 291, 641	3390 346, 762	3530 360, 794	4070 415, 915	5420 552, 1218	6100 622, 1371	7050 719, 1585	8270 843, 1859
M4	0.70	8.78	3510 358, 789	3690 376, 830	4390 448, 987	4570 466, 1027	5270 537, 1185	7020 716, 1578	7900 805, 1776	9130 931, 2053	10700 1091, 2405
M5	0.80	14.2	5680 579, 1277	5960 608, 1340	7100 724, 1596	7380 752, 1659	8520 869, 1915	11350 1157, 2552	12800 1305, 2878	14800 1509, 3327	17300 1764, 3889
M6	1.00	20.1	8040 820, 1807	8440 860, 1897	10000 1019, 2248	10400 1060, 2338	12100 1233, 2720	16100 1641, 3619	18100 1845, 4069	20900 2130, 4699	24500 2497, 5508
M7	1.00	28.9	11600 1182, 2608	12100 1233, 2720	14400 1468, 3237	15000 1529, 3372	17300 1764, 3889	23100 2355, 5193	26000 2650, 5845	30100 3068, 6767	35300 3598, 7936
M8	1.25	36.6	14600 1488, 3282	15400 1570, 3462	18300 1865, 4114	19000 1937, 4271	22000 2243, 4946	29200 2977, 6564	32900 3354, 7396	38100 3884, 8565	44600 4546, 10026
M10	1.50	58.0	23200 2365, 5216	24400 2487, 5485	29000 2956, 6519	30200 3078, 6789	34800 3547, 7823	46400 4730, 10431	52200 5321, 11735	60300 6147, 13556	70800 7217, 15916
M12	1.75	84.3	33700 3435, 7576	35400 3609, 7958	42200 4302, 9487	43800 4465, 9847	50600 5158, 11375	67400[d)] 6871, 15152	75200 7666, 16906	87700 8940, 19716	103000 10499, 23155

Thread d *(mm)*	Pitch P *(mm)*	Nominal Stress Area $A_{s,nom}$ *(mm^2)*	Property Class								
			4.6	4.8	5.6	5.8	6.8	8.8	9.8	10.9	12.9
			Minimum Ultimate Tensile Load - $F_{m,min}$ *(N) (kg,lbf)*								
M14	2.00	115	46000 4689, 10341	48300 4924, 10858	57500 5861, 12927	59800 6096, 13444	69000 7034, 15512	92000[d] 9378, 20682	104000 10601, 23380	120000 12232, 26977	140000 14271, 31473

Table 2: Experimental Bolt Test Results

Test Results from 495 Experiment						
BOLT SIZE(in)	BOLT SIZE (ft)	Area of bolt(ft^2)	mm	grade	force(lbf)	shear force (lbs/ft^2)
0.2362	0.019683333	3.04E-04	6	8.8	3606.93	1.19E+07
0.2362	0.019683333	3.04E-04	6	10.9	5064.9	1.66E+07
0.315	0.02625	5.41E-04	8	8.8	7600	1.40E+07
0.315	0.02625	5.41E-04	8	10.9	8478	1.57E+07

Using these tables allows the team to ensure that the values they are using are accurate. The team will be using the table 1 values for the rest of the calculation to ensure that the bolt calculations are consistent and accurate. The experiment conducted is also limited by the hydraulic press and is limited to bolts under 20000lbs. For the bigger bolts to mount the winch, the table 1 values must be used.

BOLT SELECTION

There are two different grades of bolts for metric threads. The first grade is grade 8.8. This is a standard bolt used in low stress situations, The next grade is grade 10.9. This grade is a hardened bolt and requires more force to break it than the lower grade 8.8 bolts. The two bolt grades can be seen in figures 1 and 2.

Figure 1 Grade 10.9 Bolt

Figure 2 Grade 8.8 Bolt

The team wishes to use the factory bolts that are supplied with the OEM bumper. This will reduce the cost for the team as well as make the bumper easier to mount and dismount by using the factory locations and hardware. The bolts for David Bui's Jeep Liberty will have to be upgraded to a larger size bolt because the factory bolt is a 6mm bolt. Based on table 1 values, this will not be a large enough diameter to support a winch and a heavier bumper. The team plans to make a support plate for the winch and bumper. This plate will be mounted to the frame of the vehicle as opposed to the original mounting location . To mount the Jeep bumper, the team plans to use either 8mm bolts or 10mm bolts. While Carson's will require 10mm to 14mm bolts. This analysis will answer the following questions. What diameter bolt is needed to mount all bumpers and winches? What grade bolt will be required to ensure there is no hardware failure? What are the prices of these bolts? What assumptions are being made?

According to the owner's manual for the 12-ton winch, 12mm and 10mm bolts are used to install the winch[4]. The winch is 12 tons so that means that the force experienced by the winch at a maximum is 24,000lbs. The bolts for the winch will each have to withstand 6,000lbs per bolt if we use four bolts to mount the winch. The winches selected for both vehicles use the same size and grade bolt for the mounting points according to their user manuals. The team believes that the smaller winch for David's vehicle will not need to be analyzed if the bolts can withstand the forces of the larger 12-ton winch.

The Chevy Silverado uses 10mm and 14mm bolts to mount the rear bumper and 10 and 12mm bolts for the front bumper. The front and rear bumper each have 8 mounting holes for the vehicles. The rear bumper has an additional hitch receiver for towing. The Silverado has a heavier bumper, and the vehicle has a heavier frame. This means the forces will be larger on the Silverado and the bolts will need to be bigger than the Jeeps.

- Jeep bolt range: 6,8,10, mm bolts
- Silverado bolt range: 8,10,12,14 mm bolts.
- Winch bolt range: 10,12,14 mm bolts

BOLT FORCE ANALYSIS

The bolt forces are a crucial factor to determine if the hardware will fail during impact. If the bolts fail, then the bumper will fall off. However, we do not want the bolts to be so strong that if there was a substantial impact, the frame of the vehicle gets bent. This would result in the vehicle being totaled. There is a fine line of being strong enough to sustain impacts but to also shear when needed. To do this the maximum force will be calculated. The applied maximum force calculation is seen in equation 1.

$$F_{max} = m\ x\ \frac{\Delta V}{t} \qquad \text{Equation 1}$$

- F_{max} is the force expected during a light impact.
- V is the velocity of the car
- m is the mass of the car and is found by dividing weight by gravity.
- t is the time or duration of the impact.

Table 3 shows the impulse forces over a range of 5 mph to 40mph for the Chevy Silverado.

Table 3: Maximum forces of the Chevy Silverado

mass	time	start V (ft/s)	end V	Force(lbf)	mph
372.67	.15	7.33335	0	18219.46	5
372.67	.2	14.6667	0	27329.2	10
372.67	.25	22.00005	0	32795.03	15
372.67	.3	29.3334	0	36438.93	20
372.67	.35	36.66675	0	39041.71	25
372.67	.4	44.0001	0	40993.79	30
372.67	.45	51.33345	0	42512.08	35
372.67	.5	58.6668	0	43726.71	40
			Average	35132.11	22.5

After calculating the average values for the Silverado, we can see that we have a maximum force of approximately 35000lbs. The average speed is 22.5 miles per hour.

For the Jeep, the only thing that changed was the mass and those values can be found in Table 4. This table shows that the average maximum force for the Jeep was approximately 16000lbs and the same average speed.

Table 4: Maximum forces for the Jeep

mass	time	start V (ft/s)	end V	Force(lbf)	mph
173.913	0.15	7.33335	0	8502.432657	5
173.913	0.2	14.6667	0	12753.64899	10
173.913	0.25	22.00005	0	15304.37878	15
173.913	0.3	29.3334	0	17004.86531	20
173.913	0.35	36.66675	0	18219.49855	25
173.913	0.4	44.0001	0	19130.47348	30
173.913	0.45	51.33345	0	19839.00953	35
173.913	0.5	58.6668	0	20405.83838	40
			Average	16395.01821	22.5

Now that we have the maximum force, we can determine which bolts will not suffice for the loads that the bumper and winch will apply. To do this we use equation 2 for each bumper because there are 8 mounting locations for the bolts. This equation lets us determine the force applied to each individual bolt.

$$Force_{bolt} = \frac{Force_{max}}{8} \qquad \text{Equation 2}$$

From this equation, Table 1 can be used to determine if any bolts are not suitable for these applications. The maximum force per bolt for the Chevy Silverado is 4375lbs per bolt. And the maximum force per bolt for the Jeep is 2,000lbs. This is under the assumption that each bolt is uniformly loaded the same and the impact would be straight on. This allows us to simply divide the force by the number of mounting holes.

To find the force for each bolt that holds down the winch, equation 3 will be used. This equation is slightly modified from equation 2 because we reduce the number of bolts holding the winch down to 4 compared to the bumper which had 8.

$$Force_{wb} = \frac{Force_{w}}{4} \qquad \text{Equation 3}$$

The winch at maximum force will be 24,000 lbs since it is a 12-ton winch. This means that each bolt on the winch will experience approximately 6,000 lbs.

The shear stress for each size of bolt was calculated using equation 4.

$$Shear\ Force = \frac{F}{A_x} \qquad \text{Equation 4}$$

The shear stress is when the force is perpendicular to the cross-sectional area of the bolt. The shear stress tells us about how the material will deform based on the applied force. Table 5 shows the calculated shear stress on the bolts and the maximum forces taken from Table 1. The shear stress is useful to know in this project because that tells us how the bolts deform.

Table 5: Bolt Shear Stress Analysis

BOLT SIZE(in)	BOLT SIZE (ft)	Area of bolt(ft^2)	mm	grade	force(lbf)	shear force (lbs/ft^2)
0.2362	0.019683333	3.04E-04	6	8.8	3619	1.19E+07
0.2362	0.019683333	3.04E-04	6	10.9	4699	1.54E+07
0.315	0.02625	5.41E-04	8	8.8	6564	1.21E+07
0.315	0.02625	5.41E-04	8	10.9	8565	1.58E+07
0.393701	0.032808417	8.45E-04	10	8.8	10431	1.23E+07
0.393701	0.032808417	8.45E-04	10	10.9	13556	1.60E+07
0.472441	0.0393701	1.22E-03	12	8.8	15152	1.24E+07
0.472441	0.0393701	1.22E-03	12	10.9	19716	1.62E+07
0.551181	0.045931783	1.66E-03	14	8.8	20682	1.25E+07
0.551181	0.045931783	1.66E-03	14	10.9	26977	1.63E+07

Using this table, we can select the correct bolts to be used in both the bumpers and ensure that the bolts will withstand a common impact.

- Silverado maximum force per bolt: 4375 lbs
- Jeep maximum force per bolt: 2000lbs
- Winch maximum force per bolt: 6000lbs

After calculating the forces in the table, the team can select and analyze the correct bolt sizes for this project. Using equation 2 we found that the Silverado needs a minimum of 4375lbs per bolt. The table shows that the smallest bolt we can use to mount the bumper is a 6mm grade 8.8 bolt. However, the bolts will not be able to withstand an impact any larger than the calculated 35000lbs. Because of this the team will not consider a bolt less than a grade 10.9, 8mm bolt. This bolt is selected to ensure that the winch force as well as any force from impact will not break the bolt. A grade 10.9 bolt is a harder bolt and has a higher shear stress for the same diameter. A single 10mm grade 10.9 bolt is also strong enough to withstand the full weight of the vehicle. For this reason, this will be the smallest bolt the team will consider. The factory bolt size for the front bumper is a 12mm bolt. The 12mm bolt can withstand 15,000-

20,000 lbf and will be stronger than the minimum requirements. This will increase the strength of the bumper and potentially still break off before damaging the vehicle. A single bolt can also withstand the maximum force for impact. This is beneficial and preferred incase the vehicle is impacted from the side. A grade 10.9 bolt would allow a larger impact to occur before the bolt breaks. This is the preferred bolt based on its strength factor and shear forces. The 12mm grade 10.9 bolt will break if the impact is too large and will not cause catastrophic failure to the vehicle. Because the bolt is well above the minimum requirements it should be able to last the lifetime of the vehicle. The 12mm bolt can also withstand the full force of the winch with only two bolts installed. This will ensure the safe use and operation of the winch and not cause any issues with the bumper being pulled off the frame when using the winch at full force. While the 14mm bolt is stronger than the 12mm bolts, the 12mm bolts provide enough resistance to not shear when we expect the forces to be at the highest magnitude. A 14mm bolt is considered "overkill" and could potentially cause the bumper mounts to be stronger than the frame.

For the 2011 Jeep Liberty we are considering much smaller magnitudes of forces. The winch, as of now, is a lighter duty winch that will experience less forces. But to ensure that the client is happy with the bumper, the team wants David to be able to bolt a 12-ton winch to his vehicle if he chooses to. The bolts that mount the winch to the bumper are supplied by the manufacturer. These bolts are 10mm and 12mm bolts. The team wants to ensure the bolts that mount the bumper to the frame can withstand the force from the winch and the maximum forces experienced during impact. The bolt considered as the best option is a 10mm grade 10.9 bolt. The main reason for this bolt over the 12mm bolt is the fact that the frame is weaker. The Jeep Liberty has a unibody frame. This means that the part the team is using to mount the bumper to is the frame and affects the whole vehicle. The team wants to prevent bending the frame if the vehicle is in a low-speed crash. The 10mm grade 10.9 bolt is strong enough to support the load from the winch and strong enough to withstand running into a larger vehicle like a 1-ton truck.

BOLT LIFE CYCLE ANALYSIS

To guarantee that the bolts chosen are the correct bolts, a factor of safety will be calculated using the following equation.

$$Factor\ of\ Safety = \frac{Ultimate\ Stress}{Allowable\ Stress} \qquad \text{Equation 5}$$

The ultimate stress is the values found in Table 1 using the lbf values.
The allowable stress is the force applied to each bolt.

Using the forces calculated in the previous sections the team can find the factors of safety for each bolt. The factor of safety the team wants to achieve with this design is a factor of safety of 2. This is considered a good factor of safety for any design. This will allow the bumpers to be more resistant to impact and force larger than the team predicts. The factors of safety were calculated using the above equation and table 6 shows the calculated results. The blue sections are the bolts the team has selected. The 10mm bolts will be used to mount the bumper to David's Jeep. The 12mm bolts will be used to mount the winches and the bumpers of the Chevy Silverado.

Table 6 Factor of Safety Calculations

Bolt size (mm)	Grade	Ultimate Stress	Allowable stress	Factor of safety (Chevy)	Factor of safety (Jeep)	Factor of safety (Jeep)
6	8.8	3619	4375	0.8	1.8	0.6
6	10.9	4699	2000	1.1	2.3	0.8
8	8.8	6564	6000	1.5	3.3	1.1
8	10.9	8565		2.0	4.3	1.4
10	8.8	10431		2.4	5.2	1.7
10	10.9	13556		3.1	6.8	2.3
12	8.8	15152		3.5	7.6	2.5
12	10.9	19716		4.5	9.9	3.3
14	8.8	20682		4.7	10.3	3.4
14	10.9	26977		6.2	13.5	4.5

The 10mm bolts have a high factor of safety for the Jeep and this is to allow David the opportunity to add a larger winch in the future. This will also add stiffness to the mounting plate the team is designing. Less bolts can also be used to mount the bumper to the frame as a result. The 12mm bolts exceed the factor of safety at 4.5 for an impact on the Silverado and 3.3 for the winch mounting. This shows that the 12 mm bolts will be a good fit for the Silverado and can help increase the strength of the bumper over the 10mm bolts. While the 10mm bolts will be a good fit for the Jeep's bumper.

BILL OF MATERIALS

A bill of materials is included in Table 7 and includes the prices of the mounting hardware the team will need to install the bumpers and winches.

Table 7 Bill of Materials [5]

Bill of Materials				
Parts	Amount	Description	Cost(individual)	Total Cost
10mm Bolt bumper	8	Grade 10.9 Bolt for the front bumper of the Jeep Liberty	1.66	13.28
12mm Bolt bumper	16	Grade 10.9 Bolt for the front bumper of the Chevy Silverado	2.69	43.04
12mm Bolt winch	8	Grade 10.9 Bolt for the winch	2.69	21.52
Bolts may be supplied with the winch or reused from the factory hardware if appropriate grade and size				77.84

CONCLUSIONS

This analysis found what size bolts will be needed to safely install the bumpers with all factors considered. The results show that 10mm bolts can be used to mount the bumper to the Jeep Liberty's frame. 12mm bolts will be used to mount the bumper to the Chevy Silverado's frame. 12 mm bolts will be used to mount the winch to the winch plate. The calculations show that all factors of safety will be above 2. The results helped show how different grades of bolts change the shear stress of the same area. This allowed the team to pick the higher-grade bolt knowing it can withstand a larger force. This analysis answered what diameter bolt is needed to mount all bumpers and winches, what grade bolt will be required to ensure there is no hardware failure, and what are the prices of these bolts. This analysis will ensure that the customer needs will be met when it comes to the strength and durability of the bumpers. By choosing the correct bolts, the team will only have to focus on the plating and frame of the bumpers to help maintain the rigidity of the design.

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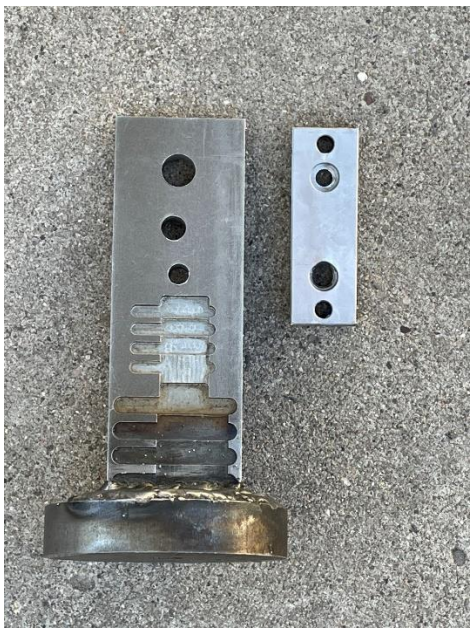
APPENDIX A: Experimental methods photos.



A-1

A-2

A-3

A-4

A-5