EAN 2019
57th conference on experimental stress analysis

Predicting methods for weight and stability performance of a new Mini Excavator

DUSANEK Tomas[1,a]

[1] Doosan Bobcat EMEA, s.r.o.; U Kodetky 1810; 263 12 Dobříš, Czech Republic

Keywords: Weight, Stability, Measurement, Design, Optimisation

Abstract. This work shows the mathematical and testing methods how to predict stability targets for a newly developed mini excavator.

Introduction

In this work it is shown how to predict weight and stability of a newly developed Mini excavator. The method developed needs to be fast and allow for major changes in the design. The goal is to use this knowledge to drive design changes and to gain confidence that final product will meet requirements.

When developing a new product, the engineers are usually faced with several requirements for the new machine. Often these requirements are in conflict. For the mini excavator there are usually these criterions in order of importance:

1) Reach, Digging depth, max height of working equipment… *(How deep can I dig?)*
2) Total weight *(Can I tow the excavator behind my car?)*
3) Length, width, height *(Will I get through the door?)*
4) Lift capacity *(Can I lift something?)*
5) ….

The engineers need to finely tune the design, to offer the best combination of the required criterions. There are also another sets of requirements that must be complied with and that are the legal (homologation) tests.

To make correct design decision having the information about weight and stability is crucial.

Mathematical model

A simple 2D model of an equilibrium in a plane had been developed. The machine does have rubber tracks on steel undercarriage. Test have been done to find the influence on the results. But with no good results. The compression of the tracks is not taken in to account.

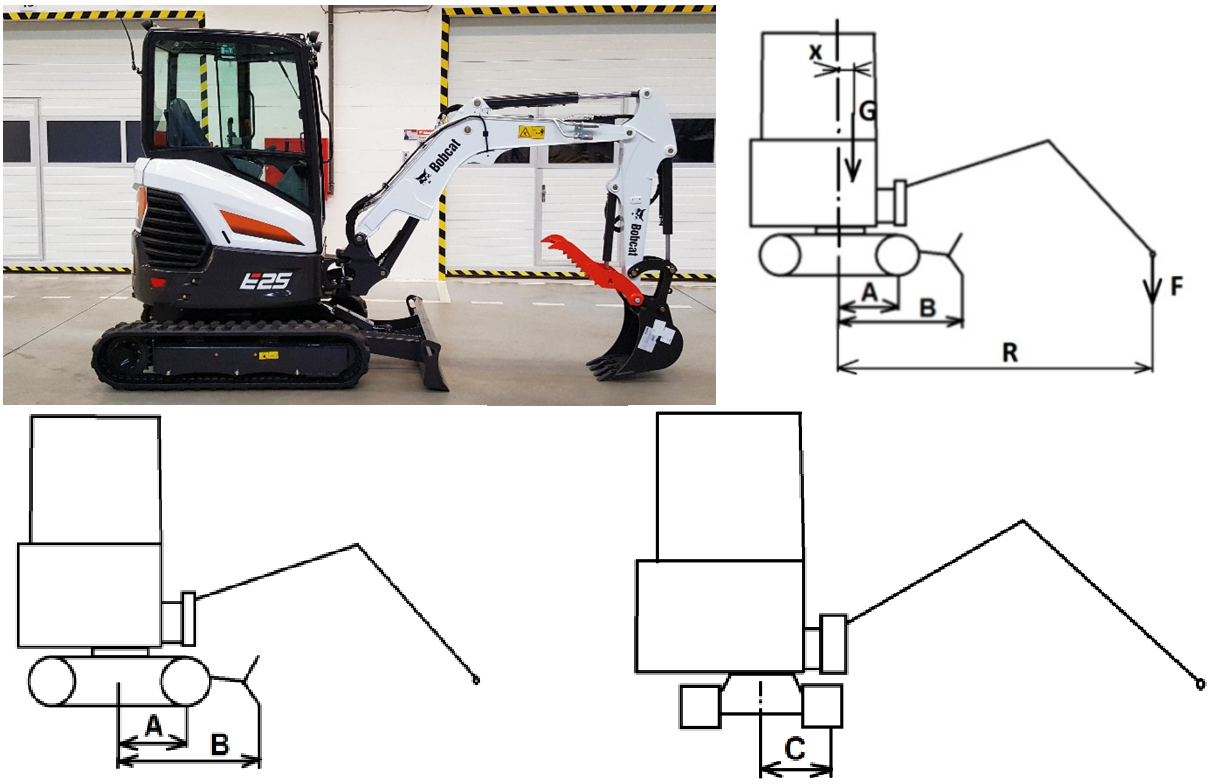

Fig. 1: Real product and simplified mathematical representation

The equation below shows the result for lifting force “F” in front position.

$$F = \frac{A-x}{R-A} \cdot G \cdot g \qquad (1)$$

similar equation is governing the stability to side load.

$$F = \frac{A-x}{R-A} \cdot G \cdot g \qquad (2)$$

The problem is how to find the weight and Centre Of Gravity (COG) position of a machine that does not exist in reality? The project is using 3D modelling software. The models have been used to find the COG and mass of each individual part in to a excel table.

Several third-party components (Cabin, hydro motors …) had been unknown. For the first estimate derived values from already known components were used.

The operation of the excavator consists of picking up dirt in front (where the biggest stability is) and dumping it on the side. The top structure including the work group is rotating on the undercarriage. That’s why it is important to know stability to front and side. When the excavator turns the “X” (front – aft) value of COG for the rotating structure changes in to “Y” (side to side) value. There fore it is not necessary to get these values from the 3D model and everything can be determined from one position of the 3D model. *(That is important because learning these values is time expensive)*

Table 1: Mass and COG position of individual parts of the machine

	Component	mi [Kg]	Xi [mm]	Yi [mm]	Zi [mm]	Xi*mi	Yi*mi	Zi*mi			
Workgroup	Swing	77.1	740	161	18	57054.0	12413.1	1387.8			
	Boom	142	1920	835	124	272640.0	118570.0	17608.0			
	Arm	97	3092	252	125	299924.0	24444.0	12125.0	Component COG [mm]		
	Bucket		2725.4	-471.8	129.6	0.0	0.0	0.0	X	Y	Z
						0.0	0.0	0.0	**1992**	**492**	**98**
						0.0	0.0	0.0			
						0.0	0.0	0.0			
	Sum	**316.1**				629618.0	155427.1	31120.8	corrected mass [kg]		**311.0**

	Component	mi [Kg]	Xi [mm]	Yi [mm]	Zi [mm]	Xi*mi	Yi*mi	Zi*mi
Upperstructure	UPSTRC W/A	273.2	51.7	165.6	26	14124.4	45241.9	7103.2
	Engine	203	-391	270	-64	-79373.0	54810.0	-12992.0
	Fuel tank	31.3	330	192	-365	10329.0	6009.6	-11424.5

Discussion about the Mathematical model

At this point a discussion is in order about what is so" *great*" about a simple equilibrium on a lever. The design process is a big compromise mainly between weight, stability and size.

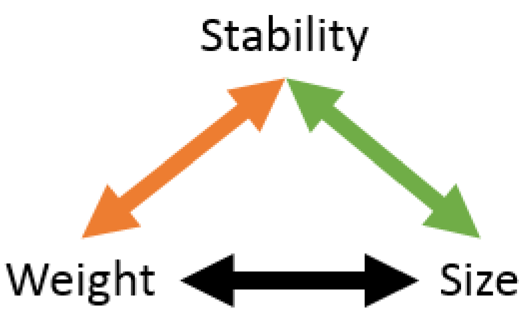

Fig. 2: Design process compromise

Ideally if our 3D models were 100% correct the machine behaviour should be predicted exactly. However, the "reality" of the design is not so simple. The models are not 100% and on top of that they are constantly changing as the design is progressing.

Also, very often the design is facing changes on the requirements. As the design progress the sales department is also working on selling the machine. And very often new or modified requirements are required from the machine. For example. The project here discussed begun as a simple "facelift" of one machine type. But during the design it evolved in to 3 different machines each with different reach, stability and weight. The engineers need to quickly and easily answer questions such as:

- It is needed for the excavator to lift weight M at a radius R. How heavy counterweight is needed?

Using the goal seek function and changing only one cell in the sheet the result is instantly available. Also, a rough estimate can be derived of how much will the new counterweight cost.

- It is needed to increase the lift capacity of the excavator. How much must be the whole upper part moved front or aft to achieve that?

  X values of COG of the Upperstructure, engine… had been linked in such a way that it could be easily modified by a fixed number. That allowed us to get several different results quickly.
- What if we change the size of the undercarriage?

  The length and width are directly responsible for stability response.
- ….

Important for the design process is to quickly show the approximate effect of the proposed change on the final product.

Table 2: Several different solutions of the excavator
The table shows what is the performance of old model compared to the new one in CANopy version, CABin version and CABin version + ADDitional Counterweight

K26 L					over blade-blade up	Over side	over blade-blade up	Over side						
	H [mm]	R [mm]	COG X [mm]	COG Z [mm]	Lift capacity [Kg]		K26 vs Target	K26 vs Target	Mass	MRD mass max 2650±30	Comparable Mass	Slew rad	Overhang	CTWT mass
E26 model CAN	0	3000	191	138	**639**	**496**	100%	99%	2495			770	20	355.0
K26 lift, CAB	0	3000	188	146	**682**	**560**	103%	100%	2651	2696		785	10	370.0
K26 lift, CAN	0	3000	191	147	**650**	**536**	99%	96%	2541	2586	2533	785	10	370.0
K26 lift, CAB + ADD	0	3000	144	104	**769**	**636**	117%	114%	2777	2822		864	89	370.0

The biggest uncertainty of the method is the 3D model which is not 100% precise. This problem is being constantly upgraded both by internal process and by the program development. For example, welds which had been only roughly approximated can be easily modelled as a solid in the new versions. It is believed that the next project will be even better at predicting the COG and mass.

To capture the above-mentioned unknowns, the first batch of prototypes had been used to corelate with mathematical model.

First prototype test

The measurement process had been subjected to Measurement System Analysis (MSA) and it had been found that the uncertainty is +-1kg (with 75% reliability).

Comparing the “real” machine to exact mathematical model has its limitations:

- the prototypes are not built to be used for weight calculations because the protypes need to represent wide variety of different configurations.

- Cabin/ canopy
- Long arm / Short arm….

To help verify the design and manufacturing process.

- The prototypes are fitted with variety of testing equipment whose weight can be in the order of 50 kg.

As many real machines as had been available were measured. Than any components that were out of our mathematical specification were subtracted or added. The results are shown below.

Table 3: comparison between test and mathematical model - mass

	Excel	Test	TR vs Excel	
	Weight	**Weight**	**Weight**	
K25	2 437	2 372	-65	-3%

	Excel	Test	TR vs Excel	
	Weight	**Weight**	**Weight**	
K27 H	2 761	2 724	-37	-1%

First iteration had been able to predict the weight with mistake between -65 and -37 kg. *The model did predict smaller weight.*

The table below is comparing our predicted lift capacities with real measurement:

Table 4: comparison between test and mathematical model – Lift capacity

			Excel		Test		Delta Test vs Excel	
			over blade-blade up	Over side	over blade-blade up	Over side	over blade-blade up	Over side
K25	H [mm]	R [mm]	Lift capacity [Kg]		Lift capacity [Kg]		Lift capacity [Kg]	
R27	0	3000	557	509	**507**	**482**	-50	-27
R29	0	3000	542	492	**507**	**482**	-35	-10

			Excel		test		Delta Test vs Excel	
			over blade-blade up	Over side	over blade-blade up	Over side	over blade-blade up	Over side
K27 H	H [mm]	R [mm]	Lift capacity [Kg]		Lift capacity [Kg]		Lift capacity [Kg]	
R27	0	3000	970	821	**910**	**775**	-60	-46
R29	0	3000	957	811	**910**	**775**	-47	-36

The measured lift capacities had been between -10 and -60 kg off from the prediction. *The model did predict smaller lift capacities.*

Discussion about the test and model correlation

Theoretically it should be possible to investigate the model and the test specimens long enough to find all the differences and tie-up the model with reality. How ever in the mean time the design is progressing. It had been decided against such approach. Measured results had been used to fine tune model by modifying some variables.

Updated mathematical model

The test did show several conclusions.

- Adding the measured weight in to mathematical model did show better results. The mass and the mass distribution are the most important input in the calculation.
- For the side lift capacity, the variable "C" needed to be adjusted by -1.6mm to conform with the testing. (This is due to uncertain "tip point". The Tip point is a result of complicated interaction between the rubber tracks and the undercarriage.)
- For the front lift capacity, the variable "A" was adjusted by -8mm. (a value measured in the laboratory) *The variable A is variable in the assembly as well. It depends on a human operator to fill the cylinder to get some approximate tension in the track. Ideally this should be measured during each test. It was not done, and mathematical model used this one adjustment.*

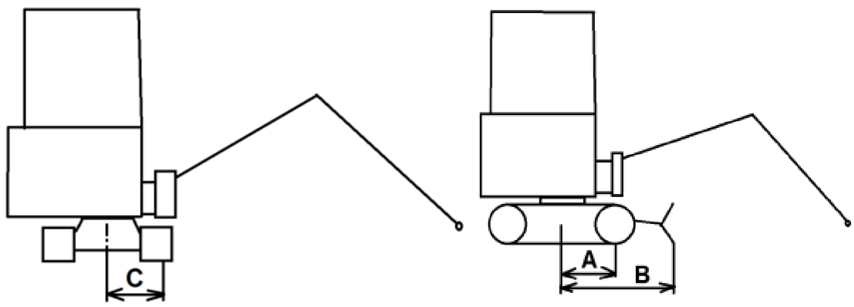

Fig. 3: variable C and A

Using these adjustments, the mathematical model had been tuned and used for the final design of the machine. Weight and stability targets for several variants of the machine had been calculated. A prototype had been built and measured. The table below shows the final comparison between theoretical model and real measurement:

Table 5: comparison between the final calculation and test – weight

	Calculated [Kg]	measured [Kg]		
	R38	-	Delta [Kg]	Delta [%]
E26	2318	2359	41	1.75%
E27z	2458	2453	-5	-0.20%
E27z Long	2472	2467	-5	-0.20%
E27	2530	2578	48	1.86%

Table 6: comparison between of the final calculation and test – Lift capacity

		R38	over blade- blade up			
	H [mm]	R [mm]	Calculated [Kg]	Measured [Kg]	Delta [Kg]	Delta [%]
E26, CAB	0	3000	620	627	6	1.0%
E27z, CAB	0	3000	682	687	5	0.7%
E27zH, CAB	0	3000	755	760	5	0.6%
E27, CAB	0	3000	781	771	-10	-1.4%
E27H, CAB	0	3000	894	884	-10	-1.1%

Conclusions

- Simple tool had been developed which helps to optimise the design.
- The first mathematical iteration is not precise enough. A correlation with test is needed to gain more precise results.
- The updated model can predict the weight of the machine with precision of -5 to +48 kg. (-0,2% to +1,86% of the whole mass.)
- The updated model can predict the stability targets of the machine with maximum mistake of +5 to -10kg. (0,6% to -1,4% of the lift capacity)