A working design of a bulldozer blade as additional equipment of a compaction drum roller

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Abstract: The main purpose of the performed works was to develop a concept of a bulldozer blade mounted to the road roller. The paper presents the main assumptions, design stages, results of strength analyses of the blade, which can be used in a road roller. Because the elements that push the components of machines operating on construction sites, in mines and in the agricultural environment, the elaborated element would enable wider use of the roller. Based on the FEM analyses, it has been confirmed that the developed load bearing structure is characterized by full operating strength. The designed blade meets the initial assumptions and can be used as equipment of heavy machines.

Keywords: heavy machinery, bulldozer blade, compaction drum roller, FEM analyses

1 Introduction

Machines fitted with a bulldozer blade are used for a variety of construction, mining and agricultural works, on industrial sites and landfills, that are also using to remove solid snow [1]. The use of a dozer blade allows processing of soil by its separation from the ground and pushing it at a small distance. The bulldozer blade is the main tool used in bulldozers and graders. The first bulldozer was built by a farmer James Cummings and a draftsman Earl McLeod in 1923 for the construction of pipelines. The basis of the design was a tractor and the blade was made from wooden planks (Fig. 1) [2].

The fundamental research problem of bulldozers is the shape of the blade that is decisive of the fashion, in which the soil moves over it, hence the processing resistance, blade filling and technological possibilities of operation, particularly the blade's capacity in relation to the machine power output. The analysis of the designs of bulldozer equipment of the most popular manufacturers indicates that at the end of the XX century, the following were manufactured and operated: typical universal bulldozers – approx. 20-30%, s-blade bulldozers 60-70% bulldozers with ball- joint blades 20-25%.

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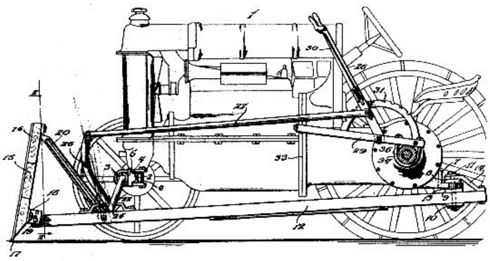

Fig. 1. McLeod and Cummings 1923 bulldozer [3]

The s-blade is the simplest design solution. It usually consists of a properly shaped steel plate (round or parabolic), set perpendicularly to the driving direction. The blade is fixed by a welded structure or ribbing. It is usually made from a hard facing steel of the hardness of 250-600 HB. On the rear wall of the blade, the frame and hydraulic jack joints are fitted. The blade is a pushing component moving the soil and the edge fixed to the bottom of the blade separates the soil from the ground. The edge has a form of one – to three-part bars fixed to the blade with recessed bolts (Fig. 2) [2].

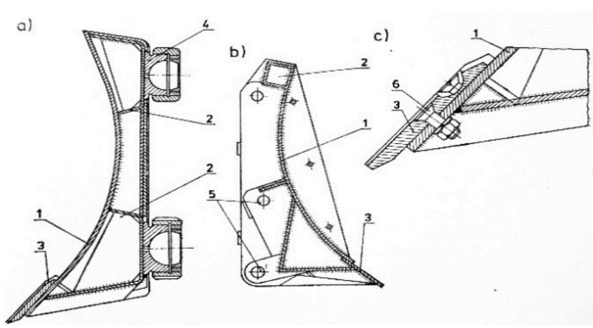

Fig. 2. Examples of the dozer blades [4]: a) ball fitting b) joint fitting c) edge fitting; 1 - plate, 2 - reinforcement ribbing, 3 - cutting edge, 4 - sockets of the ball joints, 5 - holder, 6 - edge fixing bolt

The adjustment of the cutting depth is done by the lifting mechanism that ensures angular displacement of the blade-frame assembly around the main pivots. A single bi-directional hydraulic jack is increasingly used to perform this operation. In bulldozers that are not fitted with a cutting angle adjustment, the change of this angle takes place with the change of the cutting depth, which is an obvious downside. Typical hydraulic jack fixing solutions have been shown in Fig. 3.

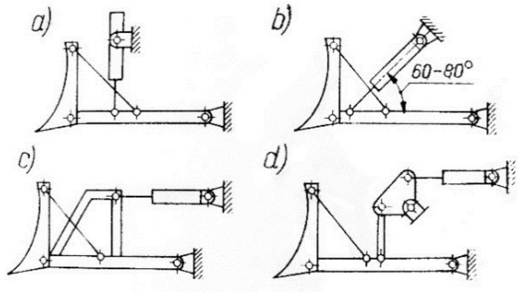

Fig. 3. Example fitting of the hydraulic jacks [5]

Basic parameters of the dozer blades are [2]:
- Blade width *B*,
- Blade height *H*,
- Cutting angle α,
- Blade skew angle ζ_S (β),
- Blade lateral lean angle ζ_P (γ),
- Blade lowering depth *g*.

Another type of dozer blades are c-type blades. The design of a c-type blade in the first place must ensure a proper lateral movement of the soil along the surface of the blade. Therefore, it usually has no sidewalls or they are significantly downsized compared with the s-blade.

The frame in the c-type dozer is basically c-shaped with a central joint. A turn around this joint allows changing the skew angle of the blade (Fig. 4). The other components of the set are usually the same as for the s-type blade.

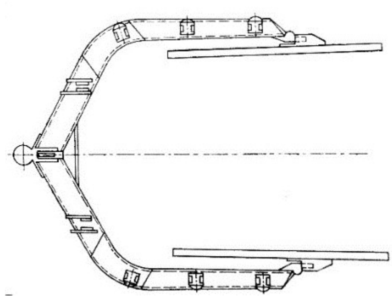

Fig. 4. C-type frame [5]

Another example of a blade is a universal blade. It combines a simple blade with a c-type blade, which provides the best operating adjustment possibilities: cutting depth, lean and skew. Similarly to the c-type blades, they do not have sidewalls. They utilize a frame in the shape of a yoke and solutions based on the same principles as a rotating plate, responsible for the process of blade leaning with a central ball joint. There are also solutions focusing on modifications of the blade design and application of additional systems as well as utilization of bulldozer components in other machines as supplementary equipment. One of such examples is a blade with a segment extendable cutting edge (Fig. 5).

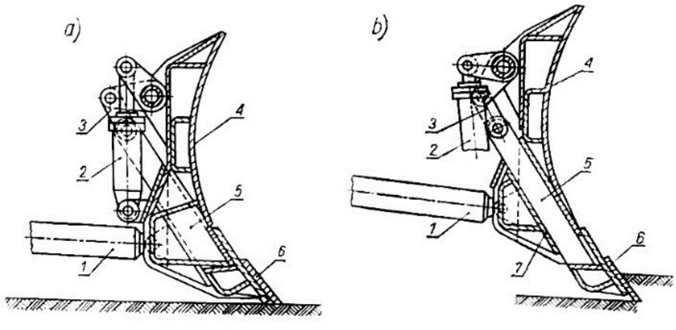

Fig. 5. Blade with an extendable edge segment: a) retracted, b) extended. 1 - the longitudinal beams of the frame, 2 - hydraulic jack, 3 - the hyphen, 4 - moldboard, 5 - the lover, 6 - the edge, 7 - the guides [6]

The main aim of this work is to develop a concept and provide a strength analysis of the designed dozer blade that could also be used as supplementary equipment of other machines [8].

2 The application of a dozer blade in a compaction drum roller

A compaction drum roller is a machine designed to develop a steady load bearing ground or surface by removing free spaces following vibration or static compaction activities. The compaction process is a significant stage of any civil engineering construction. It is used in [7]:

- construction of roads, streets, pavements, parking areas,
- construction of airport tarmacs,
- construction of earth and rock embankments, dams and water reservoirs,
- construction of railroad embankments, railroad, plaza and plant subgrades, warehouses, open areas, playgrounds, fields etc.,
- reinforcement of building foundation pits,
- reinforcement of bridge pillars and retaining walls foundation pits.

When carrying out any of the above activities one of the machines most frequently used in this process is a bulldozer or a grader. Therefore, equipping a roller with a dozer blade should give measurable results. With a single machine, it will become possible to perform a greater number of technological operations such as:

- vibration of the subgrades and surfaces,
- forming embankments,
- filling depressions and ditches,
- digging pits,
- ground leveling,
- preparation of the ground for better compaction process,
- smoothing the surface after the operation of a pegged drum roller.

A modern compaction roller has a very high power to weight ratio. Additionally, since it is propelled on both axles (tandem rollers) and owing to the application of hydrostatic propulsion, it has good traction and gradability properties. The machine's low center of gravity allows a roller to work on graded surfaces and the articulated frame facilitates maneuvering. Similarly to a wheeled bulldozer, a roller with the articulated frame will outrank a continuously tracked bulldozer in terms of higher speeds and maneuverability. All these features make a compaction roller a good carrier of bulldozer equipment. This concept is actually applied in machines. An example of such an application is the blade fitted on the BW124 Bomag drum roller (Fig. 6).

Fig. 6. An s-blade on the BW124 Bomag drum roller [2]

In the above solution a single hydraulic jack located centrally on the frame controls the lifting of the parabolic blade. It is possible to change the cutting angle manually.

It is noteworthy that the application of a dozer blade as working equipment of a compaction roller also brings along problems and limitations [1]:

- the roller frame must be sufficiently strong for a dozer blade and hydraulic control jacks to be safely installed (additional weight of 500-1500 kg),
- additional weight modifies the external parameters of the vibration system (amplitude), which may have a negative effect on the compaction process,
- the dozer equipment should be resistant to vibration during the process of compaction (vibration is transferred directly from the roller frame, hence sufficient rigidity is required),
- additional equipment increases the length of the machine – limited maneuverability and reduced angle of attack on graded surfaces,
- modifications of the roller's hydraulic system are required,
- similarly to bulldozers, if a typical frame is applied, a disadvantageous change of the cutting angle occurs depending on the lowering depth of the blade.

3 Design of the dozer blade

The design of the dozer blade should meet the following assumptions [2]:

- dozer blade should be a C-type hydraulically controlled one,
- the soil processing should be of the lowest possible energy consumption,
- the blade should have a round shape,
- cutting angle should amount to 45°,
- blade angle should be in the range 75° to 80°,
- blade lowering depth below ground should be 20 to 30 cm,
- depth of the cut layer should be 10-20 cm,
- blade Skew angle should be 25°,
- blade should be designed for processing of soil of category I - II,
- blade should have a welded structure, of unit based production.

The designed dozer equipment is dedicated for the HAMM 3412 HT/P roller. Application in a different machine is possible upon redesign of the fixing plate of the articulated quadrangle to the machine frame and ensuring proper beam strength, on which it will be fitted material which used, are researched with nearest neighbour method [1]. The bulldozer blade was design like a special devices [9].

Taking into account the solutions available in the market, their advantages, disadvantages and applications, the authors decided to develop a concept of a bulldozer C-type blade based on the articulated quadrangle (Fig. 7).

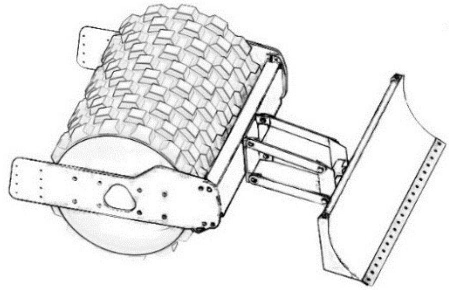

Fig. 7. The proposed design solutions of the dozer equipment view a frame in the form of an articulated quadrangle [2]

In the four-bar linkage system, the negative phenomenon of change of the cutting angle with the depth of the cut soil does not occur. This phenomenon significantly impacts the soil processing resistance. The view of the final design of the dozer blade has been shown in Fig. 8-10.

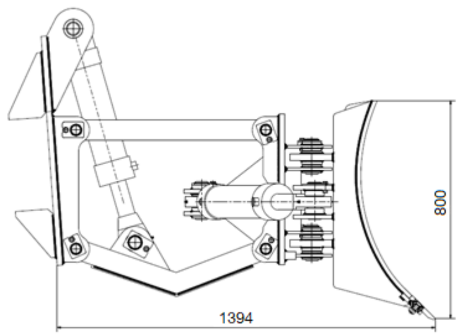

Fig. 8. Bulldozer blade– view 1 [2]

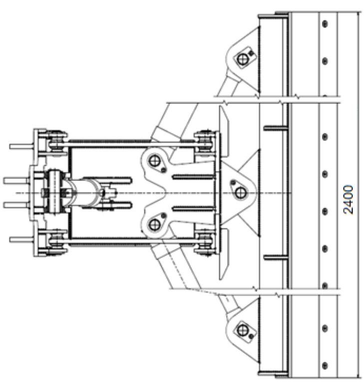

Fig. 9. Bulldozer blade– view 2 [2]

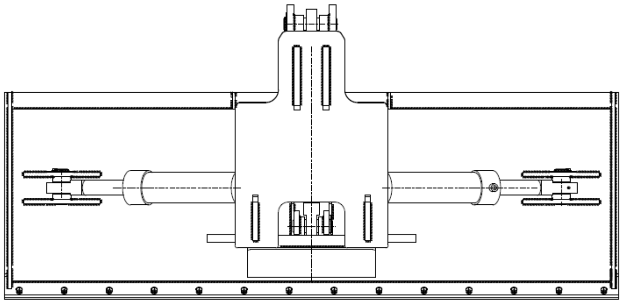

Fig. 10. Bulldozer blade– view 3 [2]

In order to perform a proper design process, the authors, aside from developing a 3D model of the dozer blade also carried out strength analyses. FEM strength investigations have been carried out with specialized calculation software. The construction of the discrete model has been shown in Figs. 11-17.

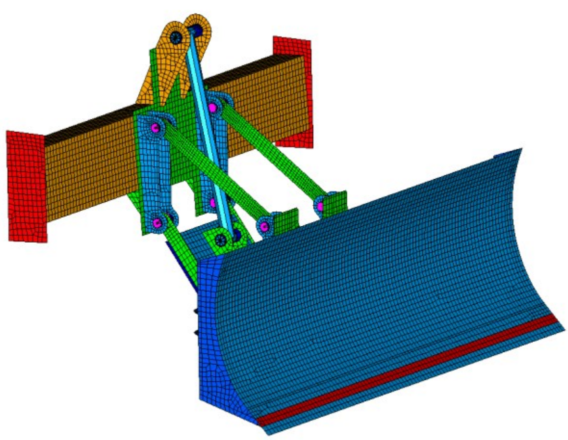

Fig. 11. Calculation model of a bulldozer blade – general view

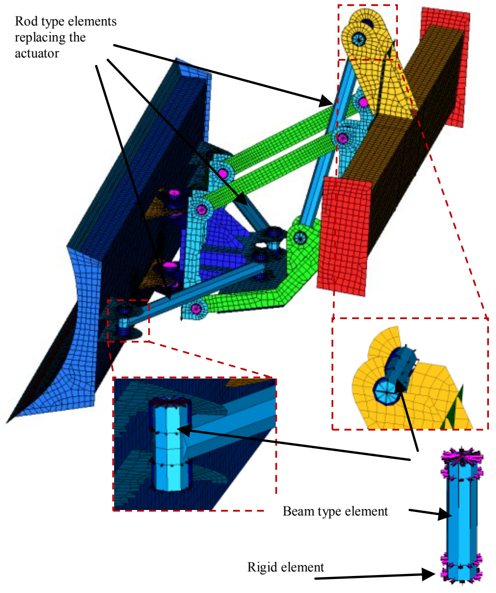

Fig. 12. Calculation model of a bulldozer blade – detailed view

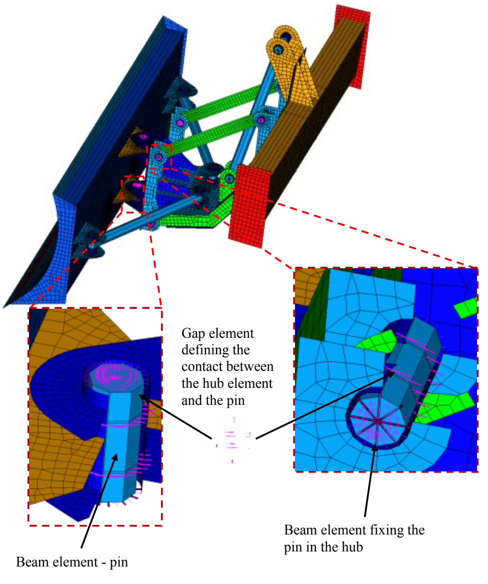

Fig. 13. Details of the joint connections

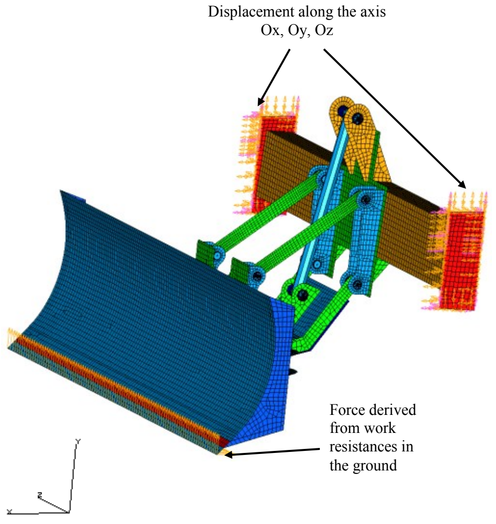

Fig. 14. Validation of the calculation model and distribution of forces

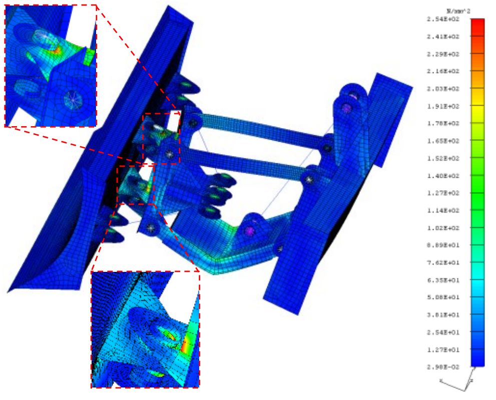

Fig. 15. Huber von Mises stress map – top view

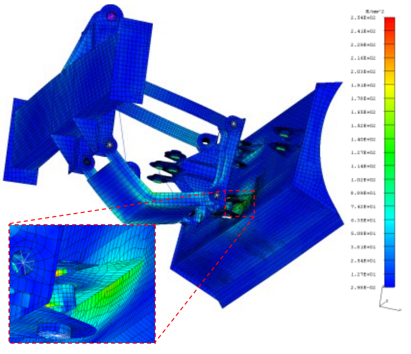

Fig. 16. Huber von Mises stress map – bottom view

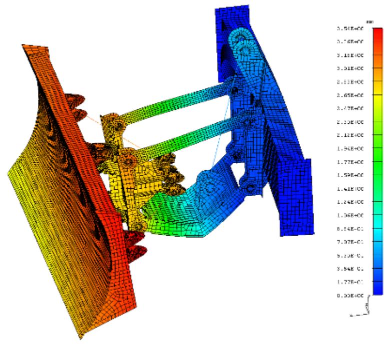

Fig. 17. Displacements of the dozer blade mesh nodes

The dozer blade was designed as a cage design, welded with RAEX 400 steel. The cutting edge will be made from the same material and will be fitted to the blade with hexagonal recessed bolts. There are four pairs of 18G2A steel supports on the rear wall of the blade – two on each side for the connection with the hydraulic jacks responsible for the adjustment of the skew angle γ and the other two as plate joints to connect the upper and the lower tension rods of the articulated quadrangle and the blade. On the upper wall, two metal sheets with bores are to be welded to facilitate displacement of the blade during fitting (for example with a workshop winch).

On the front wall, two elements constituting a limiter against excess skew of 25° are to be fitted – if the piston and the piston rod in the hydraulic jack did not have an arrest system this could lead to their damage. On the rear wall, elements are welded that connect the tension rods and a fitting system of two hydraulic jacks. Such a location of the jack fitting allows a reduction of the size of the entire equipment. On the rear wall, there are 4 elements additionally transferring load on the roller frame, to which they are welded. The plate will be welded to the roller frame. The welded connection can be replaced with a threaded connection if access to the bolts is provided. The design includes two-way hydraulic jacks.
Basic parameters of the designed equipment [2]:
- weight: 1070 kg,
- weight of the blade: 590 kg,
- max. skew angle 25°,
- blade lift: 536 mm,
- blade lowering: 273 mm,
- blade height: 800 mm,
- blade capacity: 1.4 m^3,
- width/length: 2400×1394 mm.

The cost of manufacturing was estimated based on the simplest formula – unit price per kilogram of a machine. It was ascertained upon analysis of domestic and international manufacturers of bulldozer equipment and machine spare parts. The estimated cost amounts to PLN 16000.00 [2].

An increased use of earthworks aiding and management systems based on laser, acoustic and GPS technologies have recently been noticed. Therefore, when designing any working equipment one has to allow for future installation of laser sensors for the leveling system. To this end, on the upper wall of the blade, bores should be drilled and threaded for bolts and flanges for telescopic masts should be made.

The simplest laser system *1D* is composed of a laser leveler and a laser sensor. The sensor can be equipped with a magnetic holder or can be fixed to the mast. Upon calibration, the leveler generates a rotating laser beam that is the reference plane for the sensors fitted on the working equipment. The simplest system informs the operator on the position of the equipment against the reference plane through a led gauge on the laser sensor housing [2].

4 Conclusions

In the paper the authors presented the most frequently applied solutions of bulldozer blades used in construction and farm machines. Design assumptions, and results of strength analyses of the dozer blade have also been presented. Based on these analyses, it can be observed that the designed structure is characterized by proper operating strength. No excess of admissible stresses has been observed in both the base material and the welded connections.

The developed structure may be applied as additional equipment of machines used in construction, mining etc.

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