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Kick loads from horses

Measurement of kick loads from horses on stable fittings and building elements

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***Abstract*— Fittings and fixtures in horse stables may cause injuries to horses when trapped and there is a great risk of an accident to animal and handler when releasing a horse. The risk of injuries to horses and handlers must be minimised by correct structural design and appropriate choice of building material. The physical load of horse kicks were measured in order to obtain data for the design of safe horse fittings and fixtures.**

To record the forces exerted by horse kicks a measuring wall and a computerised measuring system were constructed and used in single horse boxes. For reference, the characteristics of the measuring system were determined by a drop hammer test. Through regression analysis a linear relation was found between the field recorded impact values from horse kicks obtained by the measuring system and drop hammer impact values. The drop hammer method can thus be used to test fittings.

Impacts recorded in the field tests were rapid, often shorter than 0.03 s and 90% had a maximum value below 1924 N. The greatest impact force and impulse caused by a horse kick were 8722 N and 131 N s respectively, with no statistical difference between provoked and unprovoked kicks. Considering the data obtained and allowing a certain safety margin, the impact resistance of horse fixtures and fittings in single horse boxes, to be used for horses of up to 700 kg mass, should be at least equivalent to 150 Ns exerted by a horse shoe at 45°.

***Keywords*— horse kick, physical load, fitting, fixture, equine safety**

I. INTRODUCTION

Fittings and fixtures in horse stables, e.g. dividing grids and box wall boards or planks, may cause injuries, for instance when horses kick under-dimensioned structures and the hoof becomes trapped. In addition, there is a risk of injury to humans releasing the trapped horse. To date, according to the author's knowledge, the structural design and appropriate choice of building materials and form have been based on past experience. To prevent injuries caused by inadequate design and strength of stable fittings and fixtures, more knowledge is needed about the physical loads (force, impulse, energy) acting when horses kick items in their physical environment. Problems with insufficient strength of tubular steel grids have also focused attention on other parts of the horse box, such as windows, walls, fittings, doors, etc.

Swedish animal welfare legislation and regulations [1] require box and stall walls to have sufficient strength to withstand horse kicks and the design should exclude the possibility of horses becoming trapped by head, jaw or hoof. There are design criteria for horse stables but they do not provide mandatory material dimensions or minimal resistance to impact forces. Manufacturers are interested in guidelines and test procedures based on objective information, in order to manufacture safe equipment for horses while still meeting the demand for economical use of materials. At present horse owners/keepers, welfare inspection personnel and equipment manufacturers have difficulties in following the intentions of the welfare legislation because of a lack of objective knowledge about safe stable design. The design guidelines have to allow manufacturers and building contractors within the horse sector to fulfil the demands of the authorities.

There are none official statistics on horse injuries, according to the authors' knowledge, diagnosed as caused by horse kicks against stable fittings and fixtures. However, in a web-based inquiry short 2 % of Swedish horses get injured related to fittings within 10 years, of which the half related to box grids, sometimes with serious leg (e.g. pastern) wound as a consequence of the hoof getting trapped in the grid [2]. Other cases of hoof trapped involve skull fractures when horses tumble over and bang its head on hard floor. A scenario when a hoof gets trapped in a vertical tube grid is that the horse kick hits between the tubes and the tubes are not strong enough comparing to the energy impact and/or have inappropriate distance comparing to hoof dimensions so that the tubes yield letting the hoof pass and then bending back.

The severity of the horse kick depends on the force; a peak force from horse kicks of 19 kN has been reported from Germany [3]. However, available published information on forces experienced by the hoof and limbs comes from experimental measurements of the ground reaction force during normal locomotion or jumping. Dahlin et al. [4] showed that the maximum vertical force component acting on the forehoof of a trotter at a speed of 6.5 m s^{-1} was about 8000 N. Using a force plate, Schambardt et al. [5] recorded the ground reaction force (GRF) patterns at take-off and landing between the hooves and the of 5 Dutch Warmbloods (640 ± 24 kg) jumping a 0.8 m vertical fence from the right-leading canter. The GRF parameters were compared to averaged GRF-time patterns of 20 Dutch Warmbloods at the right-leading canter. In the trailing left forelimb, the most powerful vertical GRFs, were found, both in take-off and in landing, to average 8320 N. Comparable results from 3 examples of left forelimb GRF for jumping horses were approx. 16 N per kg body mass, equivalent to 10240 N. In a study by Kangro [6] a constructed measuring wall was used to characterize the loads from finishing pigs (90 kg). A calculated course of impacts that covered 95% of all recorded impacts had a maximum impact of 550 N corresponding to 0.6 of the animal's weight (impact weight quotient = 0.6) with a duration to maximum impact of 0.17 s and total duration of 0.42 s. The biggest load registered had duration of 0.2 s and was 2144 N, which corresponds to 2.4 times the weight of the animal.

To be able to determine the energy impact of a horse kick, the kicking velocity of the horse limb is of interest. If the movement of the horse leg kicking can be regarded as a total or a part of an ordinary swing phase at walk, trot or jumping, with a horse hind limb length of 1.35m (wither height 1.65 m) and a target height of 0.65 m above the ground level, the kicking distance could be estimated to be 1.35 m. Swing phases at walk, trot, canter and jumping are 0.44, 0.40, 0.22 and 0.20 s, respectively, according to [7], [8] and [5]. With a constant distance, the speed can be calculated at the different swing phases, which leaves a probable speed range of 3.1-13 ms^{-1} if the movement of a kicking horse hind limb can be considered to be a total or a part of the swing phase.

In 2007 a pilot investigation of material strength was conducted at Swedish University of Agricultural Sciences (SLU), former Department of Rural Buildings and Animal Husbandry, Alnarp, Sweden, using a drop hammer. The effect of impact kinetic energy on tubular steel grids was studied under specific conditions. The results showed that an artificial hoof (drop hammer mass 16 kg, drop height 2m) with a calculated kinetic energy of 324 J at impact was able to penetrate a prefabricated standard vertical tubular steel grid for horses. The grid dimensions were: tube length 730 mm with fixed ends, tube diameter 20 mm, tube wall thickness 2 mm with spacing between tubes of nominal 68 mm. The drop hammer method has recently been applied when testing and characterising different types of wood and wood-plastic composites [9].

II. AIMS AND OBJECTIVES

The overall aim of the present study was to provide data support for guidelines on designing suitable horse box fixtures and fittings and thus significantly reduce the risk of injury to horses.

The first objective was to characterise the loads exerted on the physical environment of unprovoked and provoked horses through kicks, by using a measuring wall equipped with load cells and a computerised measuring system. The measurement was to be obtained with no constraints on the horse. The second objective was to propose methods for evaluating and testing different materials and structures in order to allow new constructions of stable structures and fittings to be designed and existing systems to be improved.

III. MATERIALS AND METHODS

A. Mearsuring Wall and Drop Hammer

The measuring system was based on a measuring wall with four load sensors placed in each corner of a measuring sheet of 22 mm plywood. The sensors were connected in parallel, with a maximum load carrying capacity of nominal 20 kN per sensor, measuring compressive and tensile forces. The four load sensors were connected to an amplifier and a computer-based measuring programme.

The measuring wall construction was tested to determine whether the same values could be registered over the whole plywood sheet area. A static calibration test was made by laying the measuring wall horizontally, and placing a mass (32 kg) distributed over the plywood surface; as well as a dynamic impact calibration under a drop hammer and dropping masses (6.5, 16.5, 26.5 and 36.5 kg) from a height of 0.5, 1.0, 1.5 and 2.0 m. Ten measurements were made for each mass and height combination of the drop hammer, with the samples distributed over the plywood surface of the measuring wall.

The drop hammer used consisted of a frame, a drop shaft and a test ram, which ram could be lifted to a maximum of 2.3 m and released by a handle. The end of the ram was fitted with a horse shoe (size 2) placed at an angle of 45^o so that the shoe tip hit the target.

Describing of the measuring system, the calibration and the drop hammer, respectively, is done more detailed by [10].

B. Experimental Design

Field measurements were carried out at 3 different stables measuring kicks from in total 16 horses with body mass 500 – 660 kg. The measuring wall was placed on partition walls in horse boxes with known kicking Swedish Warmblood or Standardbred trotters; and allowed long-term, continuous measuring periods to be sampled, since the frequency of horse kicks can be low. To only measure forceful horse kicks, a triggering function was used as a sorting mechanism, thus avoiding registration of small kicks or movements less than 100 N, e.g. from a horse leaning on it. In addition to spontaneous kicks, all horses were provoked to kick. The provocations included method of feeding, the order in which the horses were taken out for exercise and by placing an unfamiliar horse and/or a horse of different sex in the neighbouring horse box.

C. *Data recording and Processing*

From the data, the following parameters were derived: horse kick maximum force, horse kick duration and time of the day and night of the horse kick. In the data processing, a paired t-test was used for recorded and theoretical calculated impulse values to determine if there were differences between original recorded impulse values by the measuring wall and theoretically calculated using the drop hammer parameters.

The force was detected using a computer based measuring program with a sampling rate of 238 Hz. Because the sampling rate of the measuring system was lower than anticipated, a cubic spline interpolation was performed in MATLAB® [11] to give an upper magnitude to the peak values. This was partnered by the original peaks representing the lower probable magnitude. By applying the cubic spline interpolation more information can be obtained from the sampled data.

IV. RESULTS

After force bouts of longer duration were removed a total of 472 values remained. Most of the impacts (90%) had a maximum value less than 1924 N. The highest maximum value obtained was 8700 N. Furthermore the total duration of registered impacts was short: 2% had duration shorter than 0.001 s, while the majority of the impacts (93%) had duration between 0.001 and 0.05 s. The distribution of the impacts through the day showed that they coincided with activities such as morning and evening feeding, but also other activities during the morning. The greatest impact caused by a horse kick registered in this investigation amounted to an impulse of 131 Ns.

V. DISCUSSION

A. *The Measruring Wall Construction*

The measuring wall construction, through the elasticity and yield of the plywood sheet material due to its dimensions and the reinforcement steel profiles along the back of the plywood sheet, could affect the recorded impulse and the possibilities for appropriately replicating the experiment.

The possibility that the drop hammer might not meet the ideal situation of free fall, e.g. that a certain amount of friction might arise along the drop hammer shaft, was not accounted for in this study. The system of unloading the sensors from the weight of the plywood sheet may also have influenced the measured results.

B. *The Measuring Wall Calibrations*

The method of using the drop hammer together with the measuring wall was successful. It was possible to use the drop hammer method as a calibration instrument for the measuring wall and in that way the field measuring values could be related to the laboratory method. The relatively steady measurement values derived when using the drop hammer on the measuring wall could characterise the measuring wall working process and indirectly give a quantitative measure of the measuring wall construction. The measuring wall was calibrated with methods that could be considered reasonably easy to replicate. Because of the lower than optimal sampling rate of the measuring system, the cubic spline interpolation was used together with the original recorded values to give an estimate of a lower and upper probable magnitude of the peak values, making the obtained horse kicking data set more robust.

C. *Field Measurement Values*

The impact duration of the drop hammer is within the range of the measured kick duration. In the present study, the range of the horse kick impact forces could be compared with the range of vertical forces from trotters [4] and jumping horses [5]. Due to the short duration of the highest recorded impact value, its impulse value was rated in 13th place. However, it is difficult to determine how representative the recorded horse kick values are in terms of maximum impact for horses in general, as only a limited number of horses were included in this experiment. An indicator of this could be that the biggest impact load from pigs was 2.4 times the weight of the animal [6] compared to 1.35 from a horse in this study.

D. *Design Considerations*

In testing materials and as a guideline for the structural design of horse boxes, the dimensioning value used has to be based on general considerations. The highest recorded impact value from the field measurements corresponded to an impulse value of 131 Ns, which is equivalent to a theoretical impact energy of 350 J (2.67 x 131), where 2.67 is the coefficient of the gradient line between theoretical calculated impulse and impact energy based on all drop hammer mass and height combinations. This impact energy is consistent with the amount of energy needed (drop hammer mass 16.5 kg, height 2 m) to deform a standard vertical tubular steel grid to penetration according to the previous pilot test performed at the Department.

The parameter of interest for designing box fittings and structures to resist horse kicks is the impact energy. As a safety margin 150 Ns is proposed instead of 131 Ns. This limit value of 150 Ns corresponds to theoretical impact energy of 400 J (2.67 - 150). Furthermore, the horse hoof velocity at impact is assumed to be 3.13-6.27 ms^{-1}, which was the velocity range of the drop hammer in the laboratory tests. It is likely that hoof velocity at impact can be faster resulting in greater impact energy in relation to impulse. Analysis of a kicking horse, filmed with an ordinary video camera (30 frames per second), indicates a hoof velocity of approx. 12ms^{-1} (range 8-16ms^{-1}) at impact. The same velocity range could be calculated based on the swing phases of trotters and jumping horses [5], [7] and [8]. This makes sense if comparing the full speed of a racing Standardbred trotter and considering the required rear hoof velocity when pushing the horse onwards. If the hoof velocity at impact is 10 ms^{-1}, the impact energy at impulse of 150 Ns will be 750 J. However, actual hoof velocities should be confirmed in future studies. Based on existing knowledge, it can be concluded that building materials and forms designed for horses up to 700 kg mass should be able to withstand at least 150 Ns impulse resulting from a point load from a corresponding horse shoe. The recorded impact values in the field experiment were increased by 15%, which can be considered to be a reasonable minimum safety margin. This consideration takes into account the fact that the largest horse included in the experiment had a mass of 660 kg and that we probably did not record the hardest kick possible by a horse.

VI. CONCLUSION

The impact of a horse kick is rapid, often shorter than 0.03 s. The greatest impact caused by a horse kick registered in the study amounted to 8722 N and 131 N s respectively. Considering the recorded values and taking into account a certain safety margin, the impact resistance requirement for conventional horse boxes to be used for maximum 700 kg horses should be at least equivalent to 150 Ns caused by a hit of a horse shoe inclined at 45^0. In order to obtain more statistically significant data, leading to more accurate design values, extended measurements, supplemented with kicking speed measurements, should be carried out on greater numbers of horses. Horses are probably able to kick harder than was recorded in our study.

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