

Safeguarding Crushing Points by Limitation of Forces

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Limitation of forces can be a simple measure to safeguard crushing points at doors, machines, and vehicles. In this connection different standards define a threshold force value of 150 N. This widely accepted value refers to static forces only. The dynamic forces that arise from impact on a person are frequently ignored, although they are generally higher than the static forces.

The article describes an instrument for the measurement of static and dynamic crushing forces. This instrument has a stiffness that approximates the average stiffness of human fingers as one of the most at-risk parts of the human body with regard to crushing injuries. Sensory tests were carried out to define dynamic forces considered admissible at crushing points.

crushing points crushing forces measurement procedure
sensory tests admissible forces

1. INTRODUCTION

Crushing points are generally defined as danger zones in architectural facilities, machines, and vehicles where components move against each other or against fixed parts in such a manner that persons may be injured. Such crushing points can be found, for example, between closing edges and counterclosing edges of power-operated doors and gates (Figure 1).

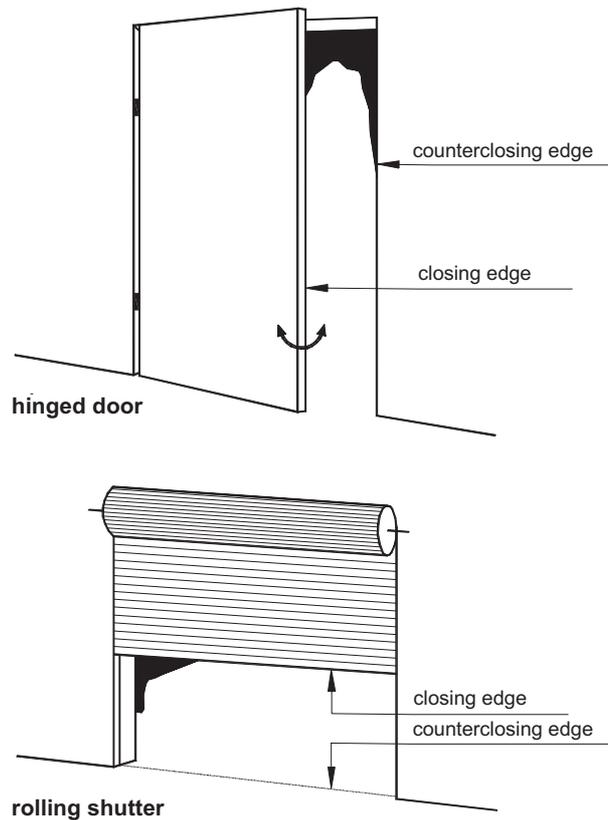


Figure 1. Crushing points between closing edge and counterclosing edge of doors and gates.

Typical injuries caused by crushing points are contusions, lacerations, and even fractures. Fingers and hands are most frequently affected (Hoffmann & Rostek, 1999; Jensen, 1987; Prechtel, 1989). In order to avoid such injuries, crushing points need to be safeguarded, for example, by creating safety distances or by installing guards, sensitive protective equipment, or light barriers. These safety measures are partly very complex and expensive. The manual operation of machines can be restricted to a certain extent by the safety devices.

If the forces acting in the crushing points are so low that no injuries are caused, the aforementioned safety measures will not be necessary. Numerous national and international standards define a maximum permissible force of 150 N in this situation (Sasse, 1996). However, this widely accepted limit refers solely to static crushing forces. The dynamic forces that arise from impact on a person are frequently ignored, although these are often significantly higher than the static forces.

Dynamic force values depend on a number of parameters. Besides the mass, speed, and compliance of the moving parts, the rigidity of the force measuring equipment used also influences the magnitude of the dynamic forces. More rigid measuring devices measure higher dynamic forces on impact than do more flexible devices because of the nature of the physics involved (Figure 2).

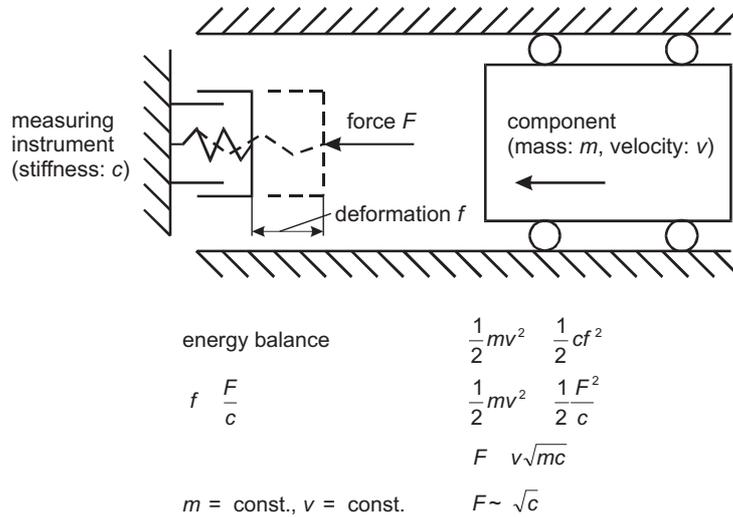


Figure 2. Influence of the measuring instrument’s stiffness on the dynamic force.

In addition to these peculiarities on the technical side of measurement, the definition of force limits is influenced by a number of additional factors, which have to be taken into consideration. These include person-specific and medical aspects as well as the technical issues (Figure 3). A lot of experimental data is available on the biomechanical resilience of human body parts, these refer primarily to the effects of car accidents and the specific forces encountered

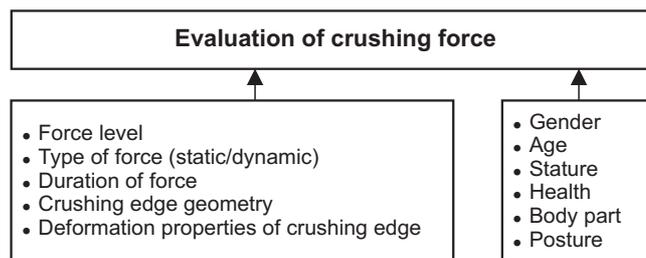


Figure 3. Examples of parameters to be considered in the evaluation of crushing forces.

here (Gülich 1988). Such studies focus mostly on the head, chest, and lower extremities. No data are available in the relevant literature on crushing-type injuries to fingers and hands as parts of the body at risk.

The present report describes a measuring device that can determine static and dynamic crushing forces. The stiffness of the measuring device is comparable to that of stiffer parts of the body, such as fingers. Sensory tests, which were carried out with volunteers, produced results about the dynamic forces that should be considered admissible at crushing points.

2. EXPERIMENTAL METHODS

2.1. Measurement of Crushing Forces

For the measurement of crushing forces the instrument presented in Figure 4 was developed. The main elements are a steel contact area of 80-mm diameter;

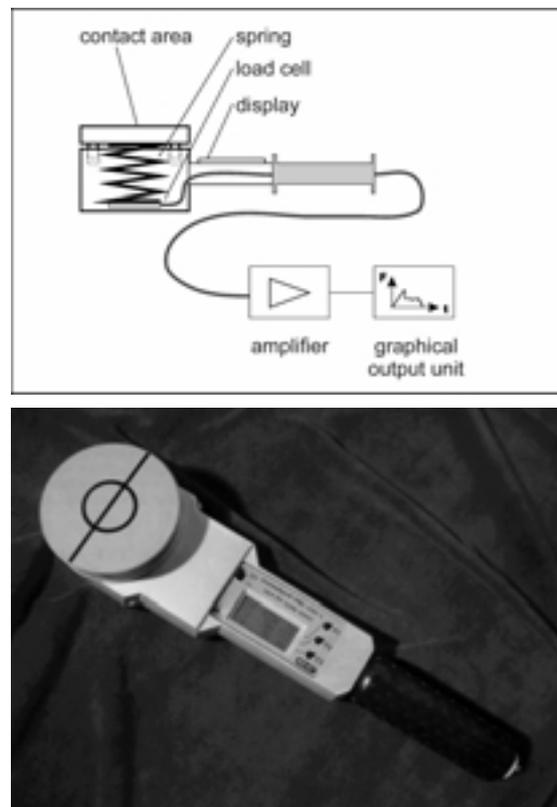


Figure 4. Measuring device for crushing forces.

a spring, which gives the instrument a stiffness of 500 N/mm; a load cell; and a display device to show the force and time characteristics. The 500-N/mm spring was selected to approximate the average stiffness of a human finger (Nykänen, 1985) as part of the body most at risk with regard to injuries caused by crushing. The instrument is only 50 mm high, so that measurements can still be taken in small gaps between components. The device weighs some 1,400 g. The measurement range lies between 25 and 2,000 N; the measuring accuracy is better than $\pm 5\%$.

The measuring device is held into the crushing point in such a manner that the force acts perpendicular to the contact area (Figure 5).



Figure 5. Use of the measuring device.

2.2. Evaluation of Crushing Forces

As the literature available offered no suggestions about dynamic force limits at crushing points, a pragmatic approach was chosen to arrive at some recommendations for permissible dynamic forces at these danger zones. In sensory tests volunteers had to evaluate different dynamic crushing forces. Eighty-five persons (25 females, 60 males) aged from 18 to 60 years participated in these tests. All participants were healthy and fully employed.

The tests were conducted on a sliding door, a hinged door, and a double folding door. Figure 6 shows an example of such an experimental setup. For safety reasons, the original drives of the doors were removed and replaced by gravity drives. Dynamic forces of different height were produced using different weights and a radial damper, which permitted adjustment to the

closing speed. Undeformable steel edges (width between 8 and 40 mm) and a deformable rubber profile (Figure 7) were used as closing edges.

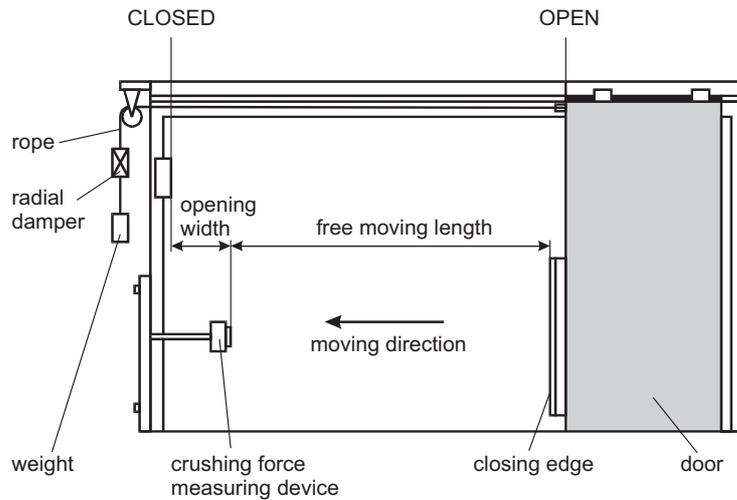


Figure 6. Experimental setup used for sensory tests at a sliding door.

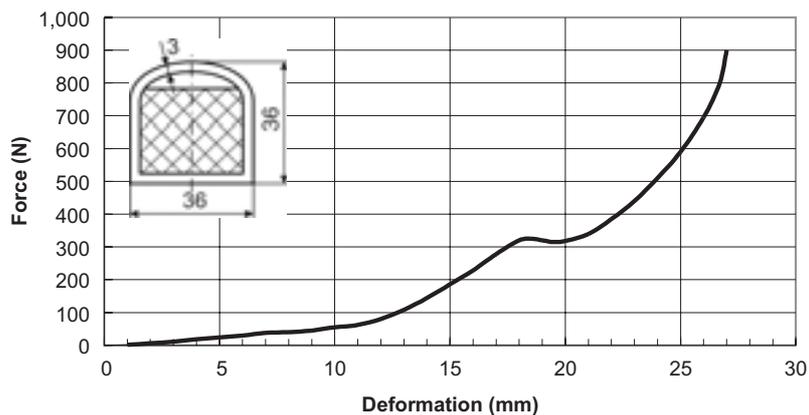


Figure 7. Geometry and deformation characteristics of the rubber profile used.

The crushing forces were measured firstly with the aforementioned device, which was mounted at the counterclosing edge. Then the measuring instrument was removed. The volunteers positioned their hand or their hip against the counterclosing edge (Figure 8). Then the door was accelerated again to evaluate the forces measured before.



Figure 8. Sensory test with the flat and extended hand.

The volunteers had to classify the different forces individually on a 3-point scale as either *well bearable*, *bearable*, or *not bearable*. Forces that did not cause any discomfort were to be evaluated as *well bearable*. The volunteers were asked to classify forces as *bearable* when they felt some pressure but no pain so that they agreed to apply higher forces. Forces that were so high that the pressure feeling changed into pain were to be evaluated as *not bearable*.

Repetitive strain in short intervals (Fransson-Hall & Kilbom, 1993) increases the sensitivity towards pain, this leads in turn to falsified results. In order to avoid this a break of at least 10 min was made before the next level of force was applied. Tests with different crushing edges were conducted on different days. To exclude reciprocal interference, each person went to the test stand individually.

3. RESULTS

3.1. Force Measurements

The performance of the developed measuring device was tested at a number of power-operated doors. Such doors are typical structures where a risk of crushing accidents is given (Figure 1). Three characteristic types of crushing force versus time diagrams could be discerned in these measurements (Figure 9). Doors equipped with a directly reversing drive, show only a short force pulse resulting from the movement of the powered component. This pulse can be adequately described by the dynamic peak force F_d and the duration of the pulse t_d . After the peak force is reached, the movement is automatically reversed. Delayed reversing drives reduce the crushing force within

the time t_d only down to that of the static motor force F_s . The reversing movement begins at a later stage. A nonreversing drive indicates the crushing force-time graph depicted in Figure 9. After the dynamic force is reduced, the motor force remains applied as a static crushing force.

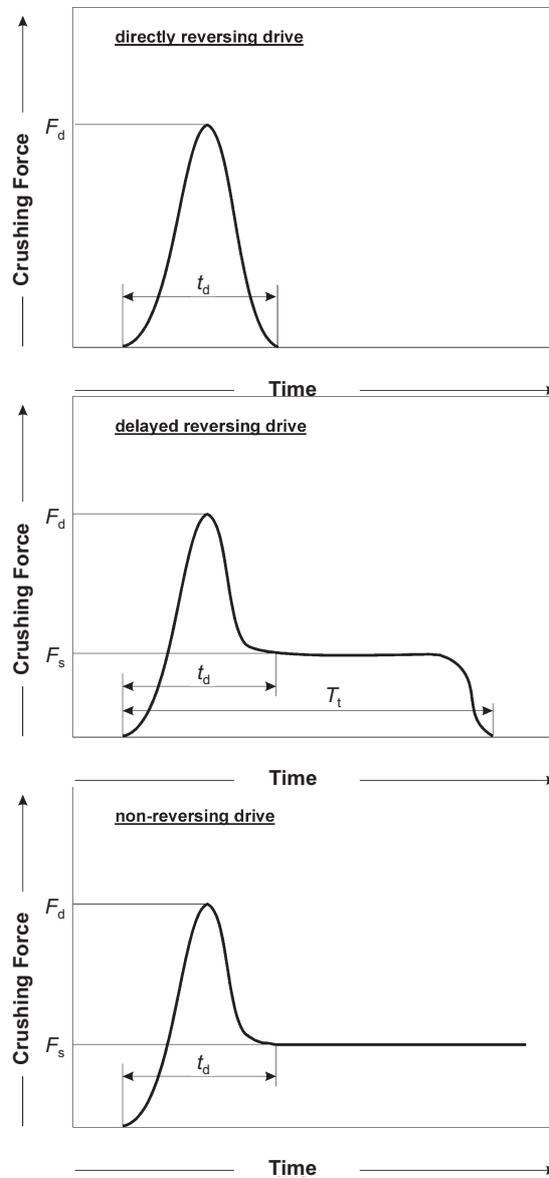


Figure 9. Characteristic crushing force-time diagrams. Notes. F_d —maximum dynamic force, F_s —static force, t_d —period of time during which the dynamic force acts, T_t —total duration of force application.

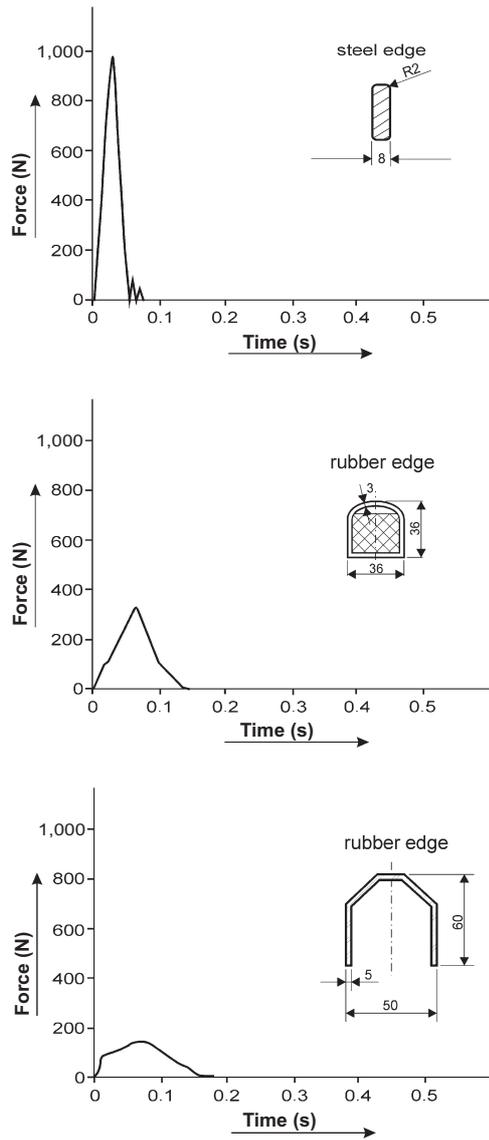


Figure 10. Crushing force versus time diagrams for different edges at uniform motor power.

The quantitative crushing force-time graph does not only depend on the mass and speed of the component, but also to a high degree on the properties of the crushing edge. Figure 10 shows results from crushing force measurements on a sliding door with a directly reversing motor. The graph clearly demonstrates how material selection and the design of the crushing edge

significantly reduces the dynamic force and the risk of injury with the same power output of the motor. Whereas a hard steel edge resulted in a peak force of almost 1,000 N, forces of around 350 or 180 N each were measured on the different rubber edges.

3.2. Sensory Evaluation

Figure 11 shows the evaluation results of dynamic forces between 200 and 500 N with the hand in a sliding door. An 8-mm-wide steel edge was installed as a crushing edge. Even dynamic forces of 300 and 400 N were mainly felt as *well bearable* or *bearable*. The majority of the volunteers considered a force of 500 N to be *not bearable*. This force was felt to be painful.

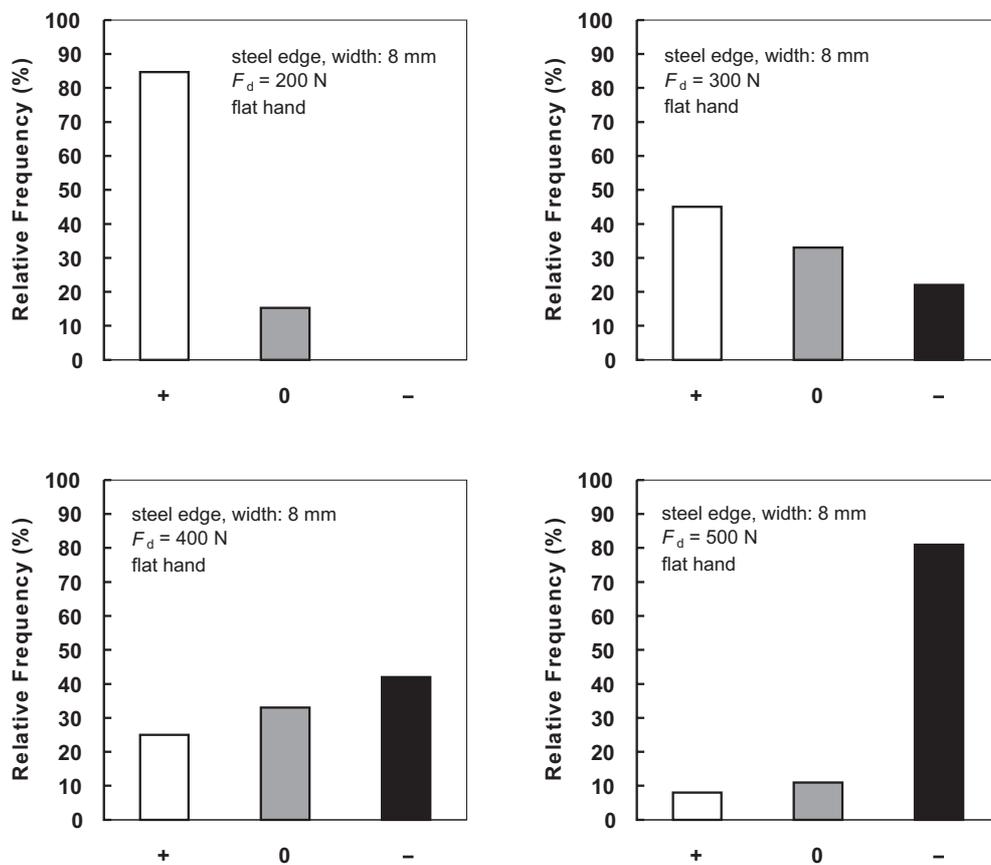


Figure 11. Sensory evaluation of dynamic forces from 200 to 500 N on the hand, held flat and extended, at a sliding door with a steel edge. Notes. +—*well bearable*, 0—*bearable*, —*not bearable*.

Yet no injuries, such as excoriations, contusions, or haematomas, were observed as a result of this force. Similar results were obtained using an 18- or 40-mm-wide steel edge.

When the crushing edges were fitted with a deformable rubber profile, the sensory evaluations were significantly better, as the forces were distributed more homogeneously over the fingers (Figure 12).

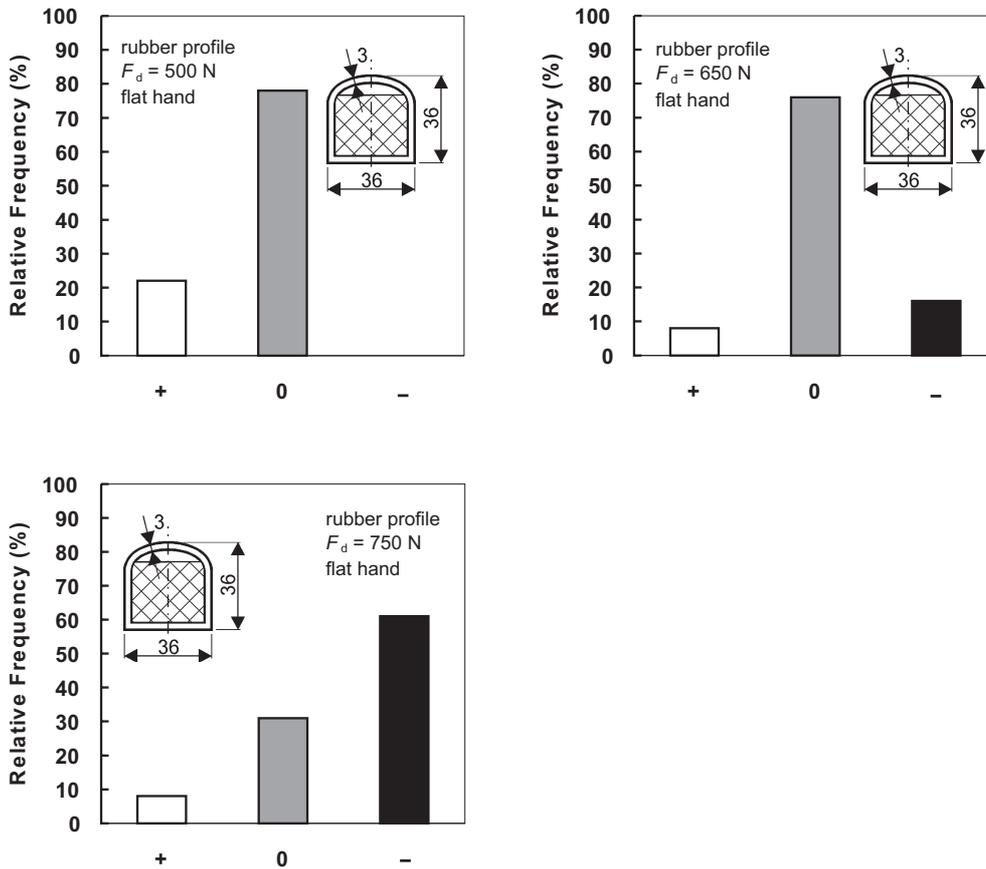


Figure 12. Sensory evaluation of dynamic forces from 500 to 750 N on the hand, held flat and extended, in a sliding door with an edge fitted with a rubber profile.

In further tests forces applied on the hip were evaluated. Even a dynamic force of 1,400 N was rated by the majority of the volunteers as *well bearable* or *bearable* (Figure 13). In contrast to sensory tests with the flat hand, the properties of the crushing edge did not influence the evaluations to a large extent. Three of the volunteers reported bruises in the hip region one day after

the tests with the sliding door equipped with an 8-mm-wide steel edge at a force of 1,600 N. Tests with even higher dynamic forces were thus not conducted.

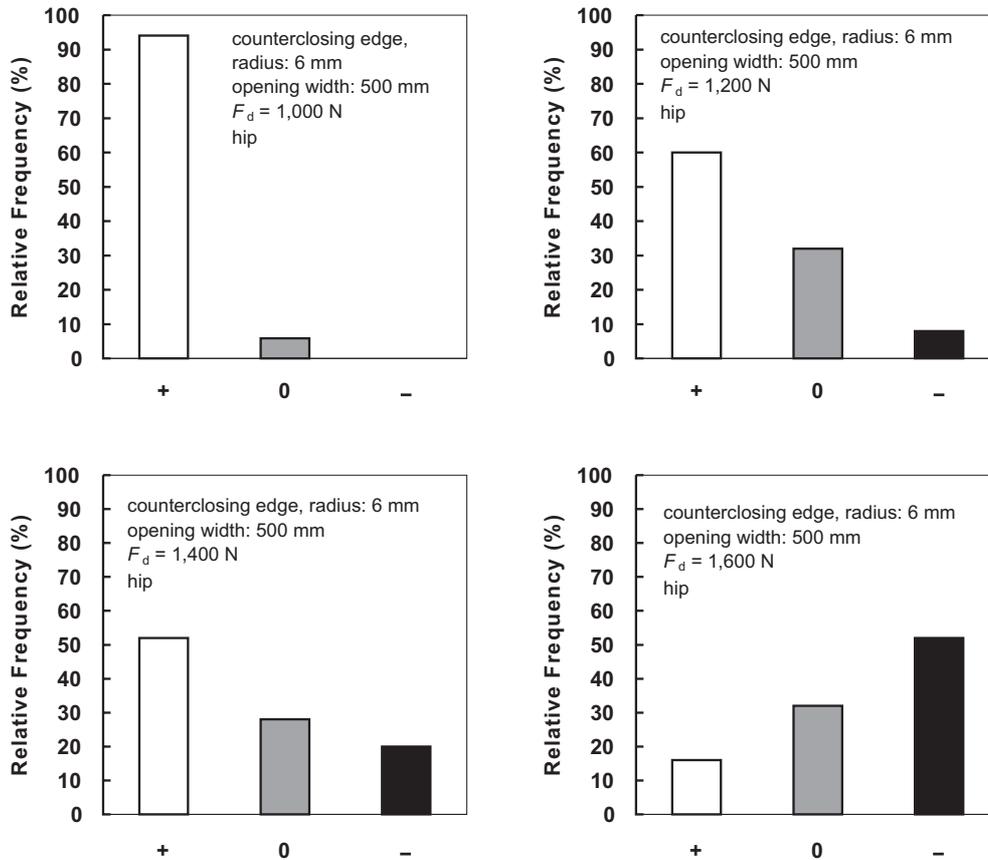


Figure 13. Sensory evaluation of dynamic forces from 1,000 to 1,600 N on the hip in a hinged door.

4. DISCUSSION AND CONCLUSIONS

4.1. Admissible Crushing Forces

The tests enable us to suggest threshold limits for admissible dynamic crushing forces at crushing points. Using the criterion that all volunteers had to describe the force as *well bearable* or at least as *bearable* in the sensory evaluations, we then achieve the figure of 200 N as admissible dynamic force for hard and rigid crushing edges in relation to fingers and hands as the

endangered parts of the body. If the hip is put under crushing strain, an admissible dynamic force of 1,000 N can be defined. The chosen evaluation procedure which was based upon the individual sense of comfort, discomfort, and pain justifies deviating from such a strict criterion and permitting higher dynamic forces, for example, 400 N for fingers and hands and 1,400 N for the hip. The majority of the volunteers rated such forces as *well bearable* or *bearable*. Also those persons that did sense these forces as *not bearable* only felt a short-term pain that disappeared immediately with taking away the force.

Due to the evaluation procedure used, all suggested limits are not to be viewed as strict biomechanical load limits where serious injuries, such as fractures, can be expected. However it should be made clear that the suggested limits cannot be considered as adequate safety measures for individuals in need of special protection, such as with the elderly, children, or the disabled. In such cases, electro-sensitive protective equipment, such as light barriers or sensor strips are adequate safety measures.

In the meantime, the threshold values of 400 and 1,400 N have been included in the European Standard No. EN 12453 (European Committee for Standardization [CEN], 2001a), which sets down the requirements for the safety of power-operated doors and gates. The limits apply to hard, rigid crushing edges as well as those with soft, deformable edges. Generally, higher forces than those suggested here, could be used with deformable, rubber-profiled edges. If these happen to be used outdoors, the profiles can embrittle due to weather influences or be damaged otherwise. As the rubber profiles would thus be rendered ineffective, it was decided not to set special limits for these edges in Standard No. EN 12453. The measurement method was included in Standard No. EN 12445 (CEN, 2001b).

It should be noted that shearing points cannot be made safe to a satisfactory degree with the same force limit values described for crushing points. As biomechanical studies have indicated, very low forces of just 50 N can themselves cause hand and arm injuries (Chapon, Verriest, & Trauchessec, 1981). Additional structural measures are required to safeguard shearing points, measures such as maintaining certain safety distances or by lining the edges with additional covering.

4.2. Conclusions

Limiting the crushing forces presents one method of making crushing points safer. This protective measure requires the forces inherent in the crushing point to be measured and to be evaluated in terms of safety engineering. The studies conducted here led us to the following conclusions:

- A distinction must be drawn between static and dynamic forces with regard to the strains at crushing points.
- The dynamic forces arise directly at impact and can thus be substantially higher than the static forces. This means that the dynamic forces have to be considered in the evaluation of injury risk.
- The level of the dynamic forces measured depends to a significant degree on the rigidity of the force measuring device used. The forces recorded with instruments of different stiffnesses and the threshold values derived from them are not comparable.
- Based upon sensory tests a dynamic threshold value of 400 N is recommended for fingers and hands as the parts of the body most at risk for crushing injuries. The measured forces are based on a measuring device with a stiffness of 500 N/mm.
- Deformable edges at crushing points can reduce the loading on human body parts in comparison to hard, rigid edges.
- Power-operated structures and components that can cause crushing injuries should be equipped with reversing drives, which reverse the movement automatically.
- The studies were primarily conducted to consider power-operated doors. However, the measuring procedure used and the threshold values suggested can also be helpful in assessing the risks of crushing injury in other moving constructions and components.

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