Determination of mechanical comfort properties of floor coverings

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Abstract

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In March 2002, the Swedish Work Environment Authority performed an inspection at Skottsundsbackens home for elderly in the municipality of Sundsvall. The Swedish Work Environment Authority came to the conclusion that the ergonomic problems many employees had experienced were related to the floor covering in the building. The municipality lodged an appeal, but in October 2005 the appeal was rejected by the Supreme Administrative Court of Sweden. In the decision you can read that "*The Swedish Work Environment Authority points out that if the floor covering has got a suitable springiness or not can not be objectively judged, since there are no test methods for this*". In spite of this, the Swedish Work Environment Authority believes that the best way to minimise the risks of strain injuries is to replace the current floor covering with a softer floor covering.

Since there are existing test methods to quantify properties of springiness (i.e. shock absorption and vertical deformation) for sport surfaces, the aim of this study has been to find out whether these methods can be applied to ordinary floor coverings. If it's possible, this might be a way of objectively judge if a floor covering is suitable or not for a certain work activity.

The test methods chosen were EN 14808 *Surfaces for sports areas – Determination of shock absorption* and EN 14809 *Surfaces for sport areas – Determination of vertical deformation.* The study could also bee seen as an inventory of what values that could be expected for ordinary floor coverings in Sweden. Another goal for the study was to find out whether or not it was possible to quantify the difference between the floor covering that was replaced at Skottsundsbacken and the softer one that was finally installed.

The conclusions of the study were that the mentioned test methods are suitable for measuring mechanical comfort properties of floor coverings, exceptions made for homogeneous and heterogeneous floor coverings without any kind of foam backing. These floorings has got very little ability to absorb energy and the results from the measurements can not be used to discriminate between them.

Keywords: Floor covering, comfort, shock absorption, springiness, vertical deformation, EN 14808, EN 14809

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Preface

Ever since the beginning of the modern athletic era, attempts have been made to improve the surface on which the athletes have been training and competing. For many years the only way to find out if the new surface was better than the previous one was by asking the athletes. Better was for long equal to the ability to break new records. The hunt for records has lead to a trend towards “faster” surfaces, today sport surfaces used at world championships etc. are specially designed to make it possible for athletes to break new records. This development results in surfaces not necessary best for training. For a better understanding of what was needed to be improved in order to get better surfaces, not only for record breaking, but also to reduce the risk of injuries, objective test methods were developed in Germany, beginning in the early seventies. This development then led to a number of DIN standards which until recently have been the standards to comply with when specifying sport surfaces.

The ability of a floor covering reducing the risk of repetitive strain injuries has not been in the mind of flooring developers until recently. Ordinary floor coverings are often sold with arguments as “easy maintained”, “good durability”, “slip resistant” etc. Maybe now is the time to start thinking in new lines.

This study was initiated since The Swedish Work Environment Authority condemned a floor covering at a home for elderly in the municipality of Sundsvall. This led to a situation where no one knew how, or if it was possible, to specify objective comfort properties for an ordinary floor covering.

I am grateful to the contributing companies who made this study possible and hope that the effort, time and money spent will pay off in their future flooring development. I am also thankful for the help I have received from colleagues at SP. Especially to Lars-Åke Henriksson who helped out with all the testing.

Borås, Sweden April 22 2009

Ingvar Demker

1 Background

1.1 Inspection at Skottsundsbacken

In March 2002, the Swedish Work Environment Authority performed an inspection at Skottsundsbackens home for elderly. The Swedish Work Environment Authority came to the conclusion that the ergonomic problems many employees had experienced, were related to the floor covering in the building. The problems described by the employees were pains in feet, knees, hip joints and lower spine. The municipality of Sundsvall was in July 2003 enjoined, under penalty of a fine, to adapt the floor covering to the current work activity, to prevent the risks of repetitive strain injuries. The municipally lodged an appeal against the decision. However in October 2005 the appeal was rejected by the Supreme Administrative Court of Sweden.

In the decision you can read that "*The Swedish Work Environment Authority points out that if the floor covering has got a suitable springiness or not can not be objectively judged, since there are no test methods for this*". In spite of this, the Swedish Work Environment Authority believes that the best solution to minimise the risks of strain injuries is to replace the current floor covering with a softer floor covering. The Supreme Administrative Court of Sweden thinks that the Swedish Work Environment Authority has come to the right conclusions and refer to The Work Environment Authority's Statute Book, AFS 2000:42, where 42 § has the following wording "*Floors shall be firm and stable and have a springiness suitable for the work activity…*".

The consequences of this is that we have a situation today, were the Swedish Work Environment Authority has formulated a requirement, on the mechanical comfort of floor coverings, that is impossible to quantify. This situation is highly unsatisfactory for the flooring business. In reality all parts, producers, suppliers, contractors, customers, users, etc. benefits from requirements that are possible to quantify. Or, even better, some kind of key levels for different work activities.

1.2 Clinical Study at Skottsundsbacken

In 2006 the floor covering at Skottsundsbacken was replaced. The floor covering that was pointed out as to hard by the Swedish Work Environment Authority was a homogeneous polyvinyl chloride floor covering of 2.0 mm thickness. The replacement was a homogeneous polyvinyl chloride floor covering of 1.5 mm thickness with a 2.5 mm foam backing. The homogeneous parts of the two floor coverings were identical in terms of colours, patterns, etc. the only differences were the thickness of the homogeneous part and the foam backing.

Since this matter had been given quite some attention by the media a clinical study was started by Jens Wahlström, Yrkes- och miljömedicin, at the University Hospital of Umeå. The study was performed as a survey through a number of questionnaires that was handed out at different times. The questionnaires were asking about employment situation, health, exercise habits, height and weight, etc. The employees also had to answer questions about pains in their feet, knees, hip joints and lower spine. If they experienced any pain they were also asked to quantify the amount of pain.

The questionnaires were handed out before the flooring was changed as well as approximately six weeks, one year and two years after the flooring was changed. As a reference, employees at another home for elderly, Lindgården, in the same municipality was used. The reference group was asked to fill out the same questionnaires at the same intervals. The floor covering at Lindgården was of the same type as the flooring that was replaced at Skottsundsbacken. There was no significant difference in age distribution nor BMI-distribution (Body Mass Index) between the two groups. Neither were there any differences in how long time ago the employees had retrieved new shoes.

The result of this study is that there are a significant change in the group at Skottsundsbacken regarding reduced pain in feet and lower spine six weeks after change of flooring. One and two years after the floor change the alteration still is significant regarding reduced pain in feet.

1.3 Choice of Test Methods

How to measure the mechanical comfort of a floor covering is not easy to decide. However, for many years, in the area of sport surfaces, there have been methods to determine how the floor responds to an athlete. Sport surface scientists in Germany have measured "Kraftabbau" (Force reduction) and "Standardverformung" (standard deformation) since the end of the 1970's. The test equipment which was further developed during the 1990's have got the name "Künstliche Sportler 95" or "The Artificial Athlete". The test methods are also known as "Artificial Athlete Berlin Modified" and "Artificial Athlete Stuttgart" respectively. One of the places where these methods can be found is in the German standard DIN V 18032-2:2001 *Sport halls - Halls for gymnastics, games and multi-purpose use - Part 2: Floors for sporting activities; Requirements, testing*. In 2005 the two methods were published as European standards with the following designations: EN 14808 *Surfaces for sports areas – Determination of shock absorption* and EN 14809 *Surfaces for sport areas – Determination of vertical deformation.*

SP Technical Research Institute of Sweden has got the necessary equipment and is, since march 2008, accredited by SWEDAC, the Swedish Board for Accreditation and Conformity Assessment, to perform these tests.
Naturally, neither the floor nor the user are subjected to the same load when walking or standing as during sport activities. Even so, the methods still offer an interesting way of trying to quantify the mechanical comfort properties of a floor covering.

2 Purpose and Aim of the Study

The primary object with this study has been to gather information on mechanical comfort properties of different floor coverings. A number of different issues had been addressed and the hopes were to get answers to the following questions:

- Is it possible to measure mechanical comfort properties with the test methods described in EN 14808 *Surfaces for sports areas – Determination of shock absorption* and EN 14809 *Surfaces for sport areas – Determination of vertical deformation*?
- What values do traditional floor covering materials have regarding shock absorption and vertical deformation?
- Is it possible to measure differences between a 2.0 mm homogeneous PVC-floor covering and the same floor covering with a 2.5 mm PVC-foam backing?

In the longer run, the result of this study may become a guide for specifying authorities as the Swedish Work Environment Authority, The National Board of Housing, Building and Planning – Boverket, Hus-AMA, etc.

2.1 Limitations of the Study

When making a floor covering softer, i.e. with a greater springiness, it can be assumed that a number of other properties will be affected. Some properties will be affected in an undesired way, such as residual indentation and rolling resistance. There are probably more properties that might be changed in an unfavourable direction, for instance the reaction to fire classification. Similarily, some properties will instead change in a desired direction, for example heat dissipation and acoustic properties. This study will not further test nor speculate in what way other properties might change with increasing mechanical comfort.

3 Materials and Methods

3.1 Contributing Companies

The following companies have not only made their flooring materials available to this study but have also served as financiers:

- Aprobo AB
- Ardbo Golv AB
- Ehrenborg & Co AB
- Forbo Flooring AB
- Boidé Gerflor Scandinavia AS
- AB Gustaf Kährs
- maxit AB
- nora systems GmbH
- Pergo AB
- Tarkett Sverige AB
- Tarkett AB
- Trelleborg Industri AB

3.2 Tested Materials

A total of 51 different flooring materials have been tested. The materials ranged from a cement based screed material to a sport floor of multi-layer parquet. The materials were arranged in the following groups:

- Heterogeneous or homogeneous resilient floor coverings without shock absorbing backing (i.e. plastic, linoleum and rubber)
- Heterogeneous or homogeneous resilient floor coverings with shock absorbing backing (i.e. plastic, linoleum and rubber)
- Textile floor coverings
- Area-elastic floors (i.e. laminate floor coverings, multi-layer parquet and other click floors)

3.3 Test Methods

It is obvious that to quantify the mechanical comfort property of a floor covering more than one property needs to be determined. This study have focused on two properties: Force reduction/shock absorption and vertical deformation.

3.3.1 Force Reduction

The force reduction is determined according to the European standard EN 14808 Surfaces for sports areas – Determination of shock absorption. The purpose of this method is to compare the tested surface to a completely rigid floor construction, i.e. a concrete floor of a significant mass. The method measures how much of the impact force that is absorbed of the floor construction. When testing, a mass of 20 ± 0.1 kg is dropped from a height of 55 ± 0.25 mm on to a spiral spring with a spring rate of 2 000 ± 60 N/mm. The spring rests on a load cell able to continuously record the force during the impact. The maximum impact force can be calculated with the following equation:

$$F_{\max} = mg\left(1 + \sqrt{1 + \frac{2hk}{mg}}\right)$$

Where:
$F_{\max}$ = Theoretical maximum force registered by the load cell in N
m = The mass of the weight in kg
g = The standard gravity, 9.80665 m/s²
h = The drop height in m
k = The spring rate in N/m

This theoretical value will be approximately 6.78 kN if the mass of the spring is added to *m*. When performing a test $F_{\max}$ needs to be determined by means of a calibration, and according to the standard $F_{\max}$ shall be 6.60 ± 0.25 kN.

The force reduction, *R*, is calculated with the following equation:

$$R = \left(1 - \frac{F_t}{F_r}\right) \cdot 100$$

Where:
Ft = The measured maximum peak force for the test piece in N
Fr = The reference force from calibration on concrete in N

Therefore the force reduction expresses how much better the tested floor absorbs the impact force than a concrete floor.

When testing, three drops are made at the same spot. An average is then calculated from the last two drops.

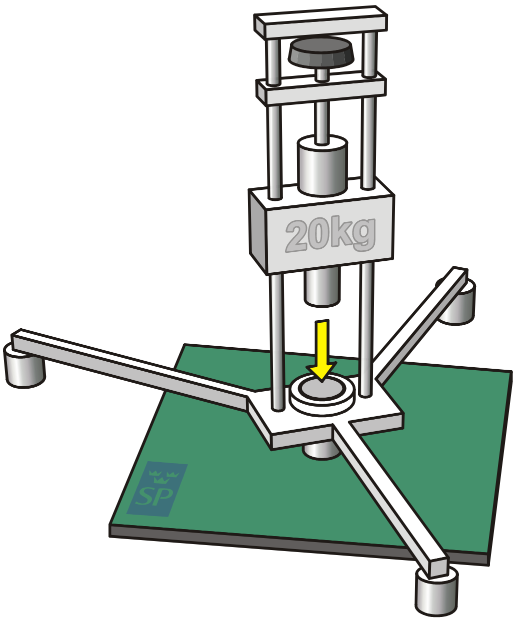

Figure 1 Artificial athlete apparatus, arrangement for determination of shock absorption

3.3.2 Vertical Deformation

The vertical deformation is determined according to the European standard EN 14809 Surfaces for sports areas – Determination of vertical deformation. This method determines the deflection of the floor surface during an impact. The equipment used is the same as for measuring shock absorption, except for the spring and a beam supporting two displacement probes. The spring rate of the spring used in this test is 40 ± 1.5 N/mm and the drop height is 120 ± 0.25 mm. This gives a theoretical maximum force of 1.58 kN. The vertical deformation, D is calculated from the following equation:

$$D = \left(\frac{1500\text{N}}{F_{\max}} \right) \cdot f_{\max}$$

Where:
F_{max} = The maximum force during test (peak value) in N
f_{max} = The deformation of the floor in the falling weight axis in mm (mean maximum of the pick-up values at each time)

Thus, the vertical deformation, *D*, is a normalized deformation expressed in mm.

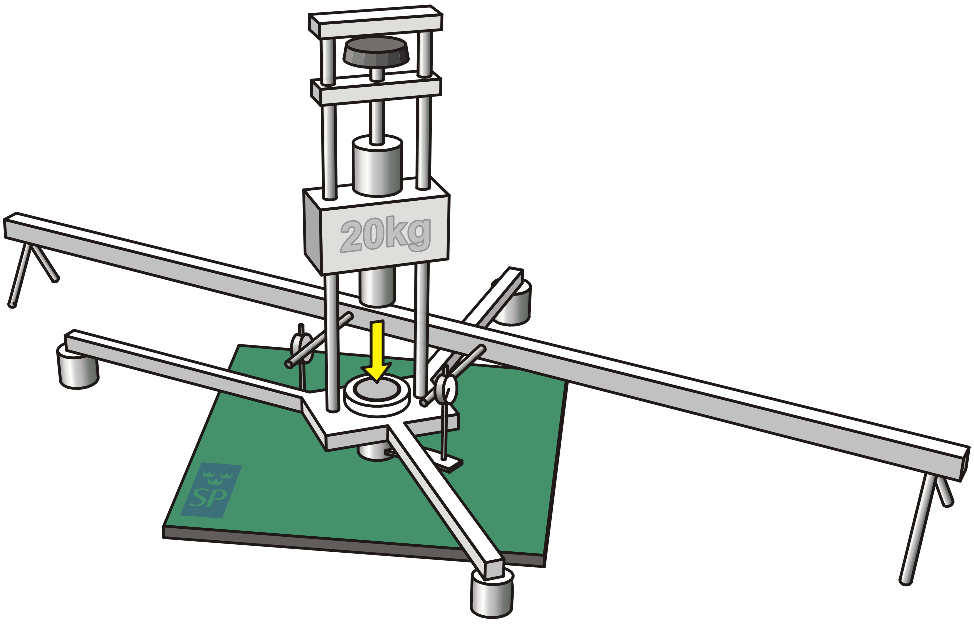

Figure 2 Artificial athlete apparatus, arrangement for determination of vertical deformation

3.4 Spring Rates

As mentioned above, the two methods use springs with different spring rates, 2 000 N/mm and 40 N/mm respectively. This way the time to maximum peak is different for the two methods. The origin of this is the study of a standardised running step where a first peak is reached after 0.016 s and another peak is reached after 0.09 s. When calculating the time to maximum peak the following equation can be used:

$$t_{(v=0)} = \frac{\pi}{2}\sqrt{\frac{m}{k}}$$

Where:
$t_{(v=0)}$ = The time to maximum peak force is reached in s (velocity is equal to 0)
m = The mass of the weight in kg
k = The spring rate in N/m

Using the equation for the two setups gives the results 0.005 s and 0.035 s respectively. This is true when measuring on a concrete flooring. The time to peak force will be prolonged by a floor covering that absorbs part of the impact energy.

3.5 Measurement uncertainty

3.5.1 Force Reduction

The uncertainty of the method depends on the measurement uncertainty of the load cell, the resolution of the load cell, the drop height range and the result (standard deviation) from the determination of the reference force.

For the equipment used the expanded uncertainty (U) of the method, based on a standard uncertainty multiplied by a coverage factor, k = 2, will vary from 0.3 to 0.7 percentage units depending on the peak force registered. The higher the force (lower result), the higher the measurement uncertainty. This uncertainty will provide a level of confidence of approximately 95 %.

3.5.2 Vertical Deformation

The uncertainty of the method depends on the measurement uncertainty of the load cell, the resolution of the load cell, the drop height range, the measurement uncertainties of the displacement probes, the resolution of the displacement probes and the construction (stability) of the test equipment.
For the equipment used the expanded uncertainty (U) of the method, based on a standard uncertainty multiplied by a coverage factor, k = 2, will be approximately 0.1 mm. This uncertainty will provide a level of confidence of approximately 95 %.

4 Results

4.1 Heterogeneous or Homogeneous Resilient Floor Coverings Without Shock Absorbing Backing (i.e. Plastic, Linoleum and Rubber)

The tested floor coverings in this group had a product thickness of 2.0 to 3.5 mm, except for the cement-based screed material which also is accounted for within this group.

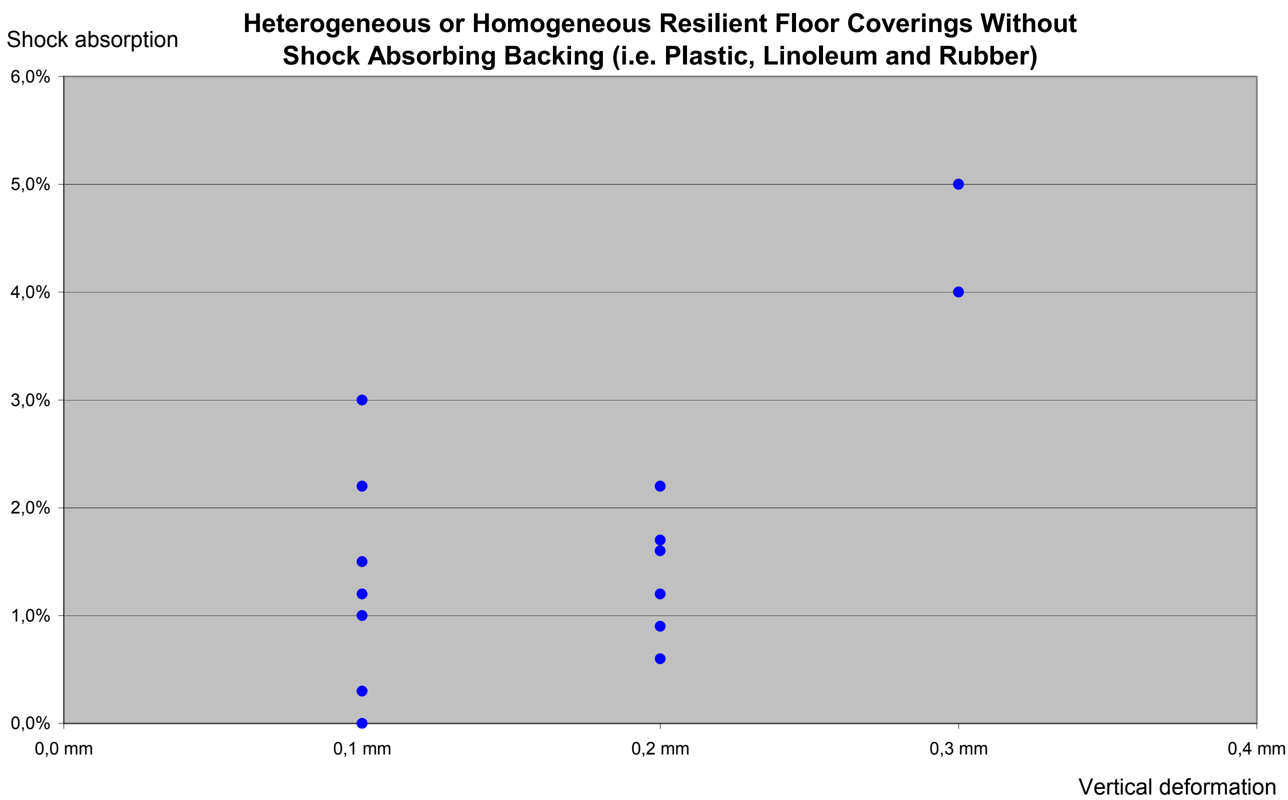

Chart 1 Results, Shock absorption plotted against vertical deformation

Chart 1 may look a bit odd, but the reason for this is that the resolution of the test equipment is ± 0.1 mm. Hence the column-looking chart instead of a normal scatter that probably is the true picture. The resolution for shock absorption is ± 1 % but for these low results the readings have been recalculated to show more accurate values. See paragraph 3.5 for information on measurement uncertainties.

4.2 Heterogeneous or Homogeneous Resilient Floor Coverings With Shock Absorbing Backing (I.E. Plastic, Linoleum and Rubber)

The materials in this group had a total thickness of 2.0 to 8.0 mm. The thickness of the shock absorbing backing ranged from 1.0 to 3.2 mm. One exception is the outlier with 2.6 mm deformation. This is a workplace matting with 6.0 mm backing.

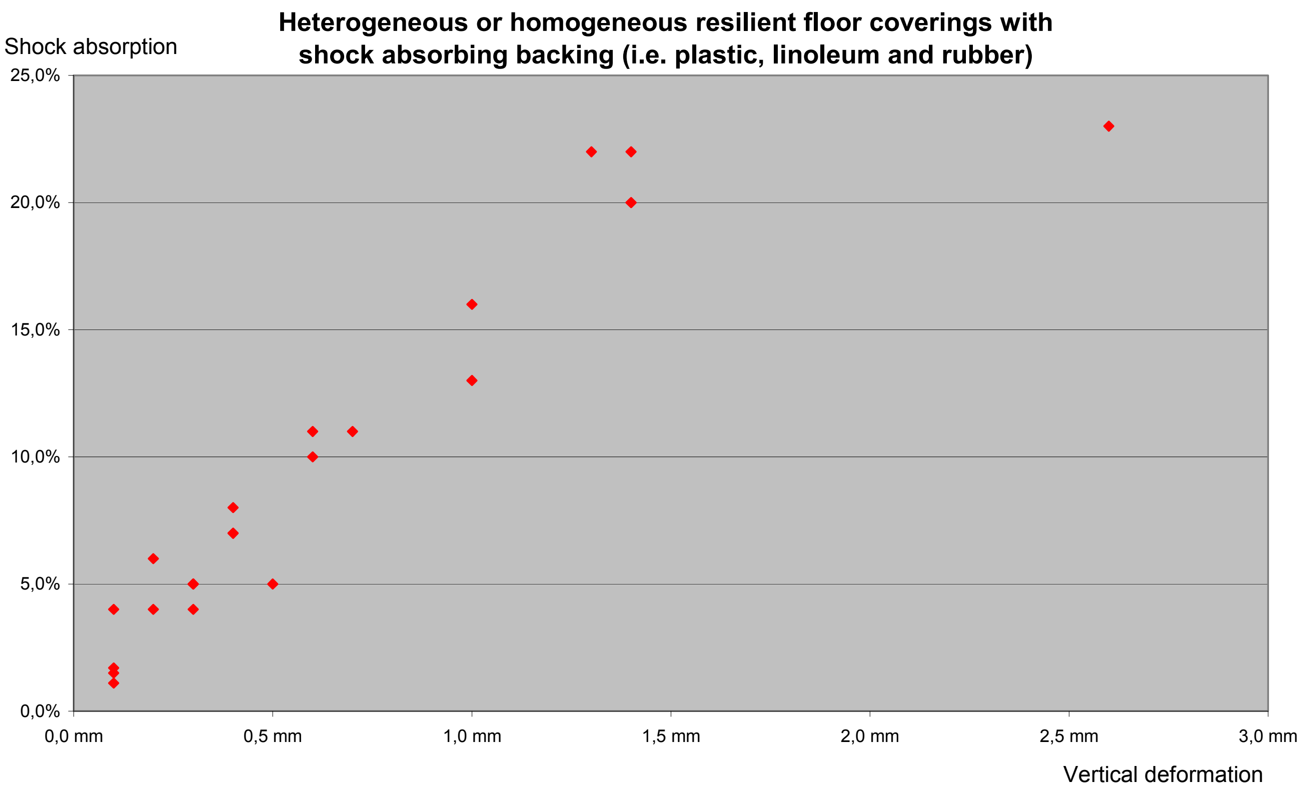

Chart 2 Results, Shock absorption plotted against vertical deformation

4.3 Textile Floor Coverings

The group with textile floor coverings only contained three materials. The thickness ranged from 4.3 to 6.0 mm.

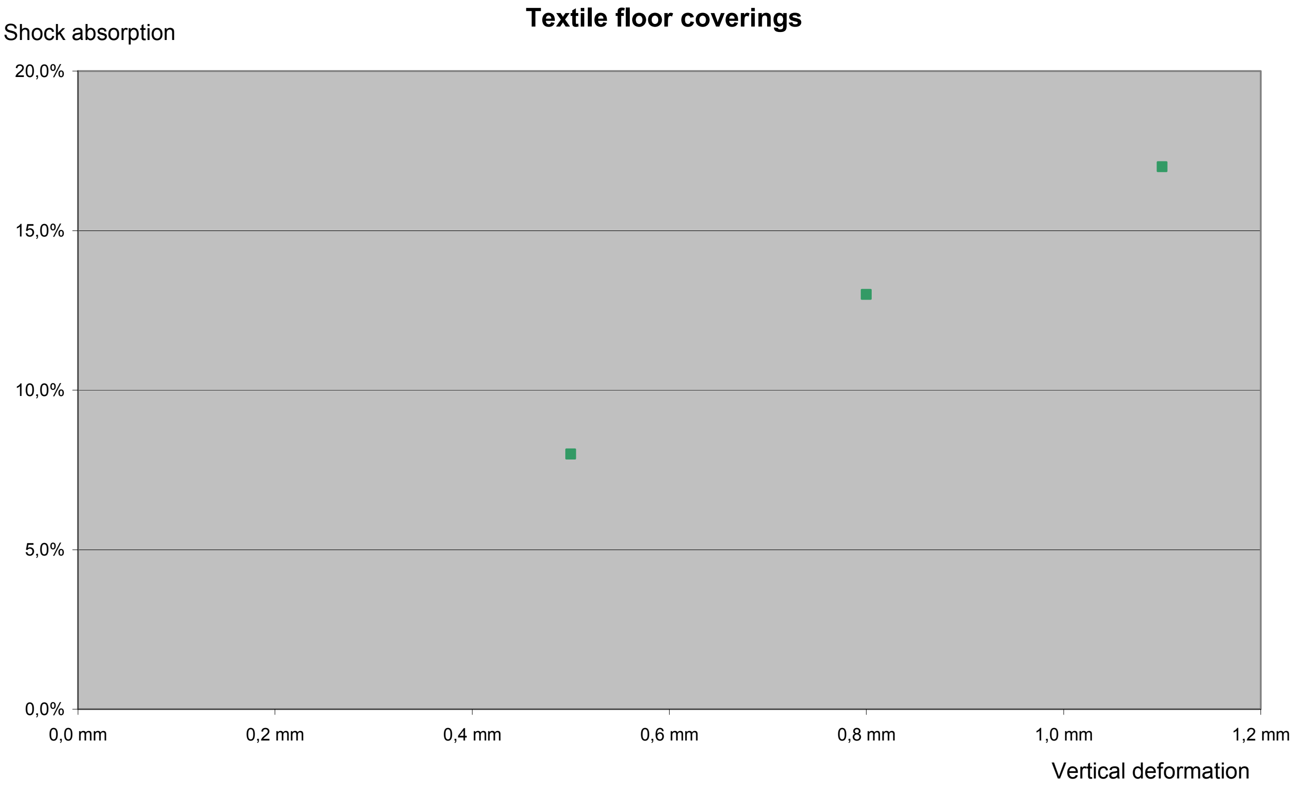

Chart 3 Results, Shock absorption plotted against vertical deformation

4.4 Area-Elastic Floors (I.E. Laminate Floor Coverings, Multi-Layer Parquet and Other Click Floors)

Nine different constructions were tested. The underlays/backings varied from a thin cork foil to a five mm thick cellular rubber foam. The single value with a shock absorption of 64 % comes from a sport floor construction.

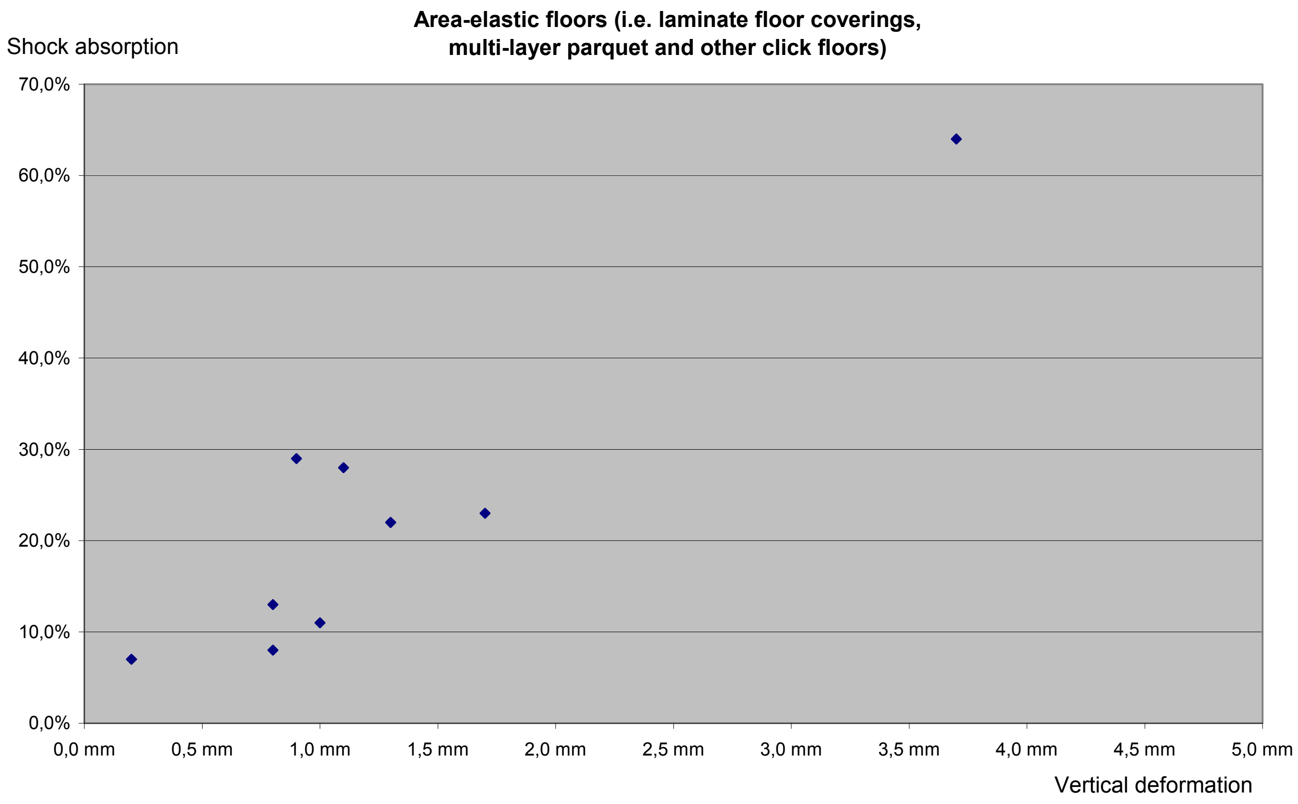

Chart 4 Results, Shock absorption plotted against vertical deformation

All of the tests has been done in the centre of a panel but the result will of course differ if tested in a joint. Therefore all materials were tested a second time in a T-joint.

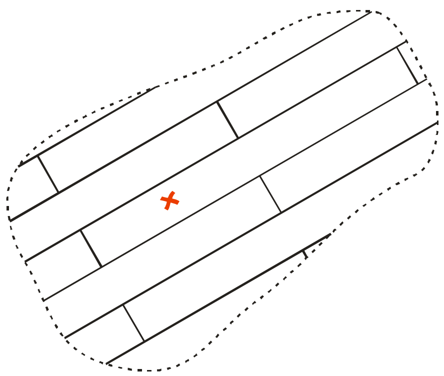

Figure 3 Test position 1, centre

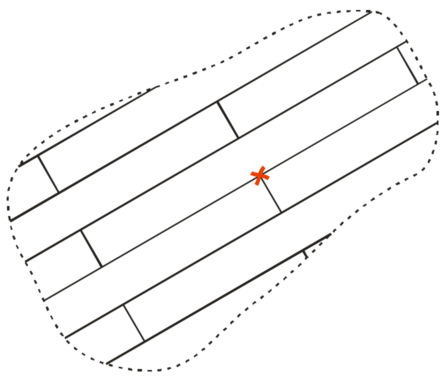

Figure 4 Test position 2, T-joint

It would be easy to assume that all results from testing in a T-joint should change in the same direction compared to the result from testing in the centre of a panel. This assumption, however, is only partly true. The shock absorption result turns out to be similar or lower for all tested material. On the other hand, depending on the construction of the click joints, the vertical deformation could change in any direction. Next chart shows how the results of the tested materials changed.

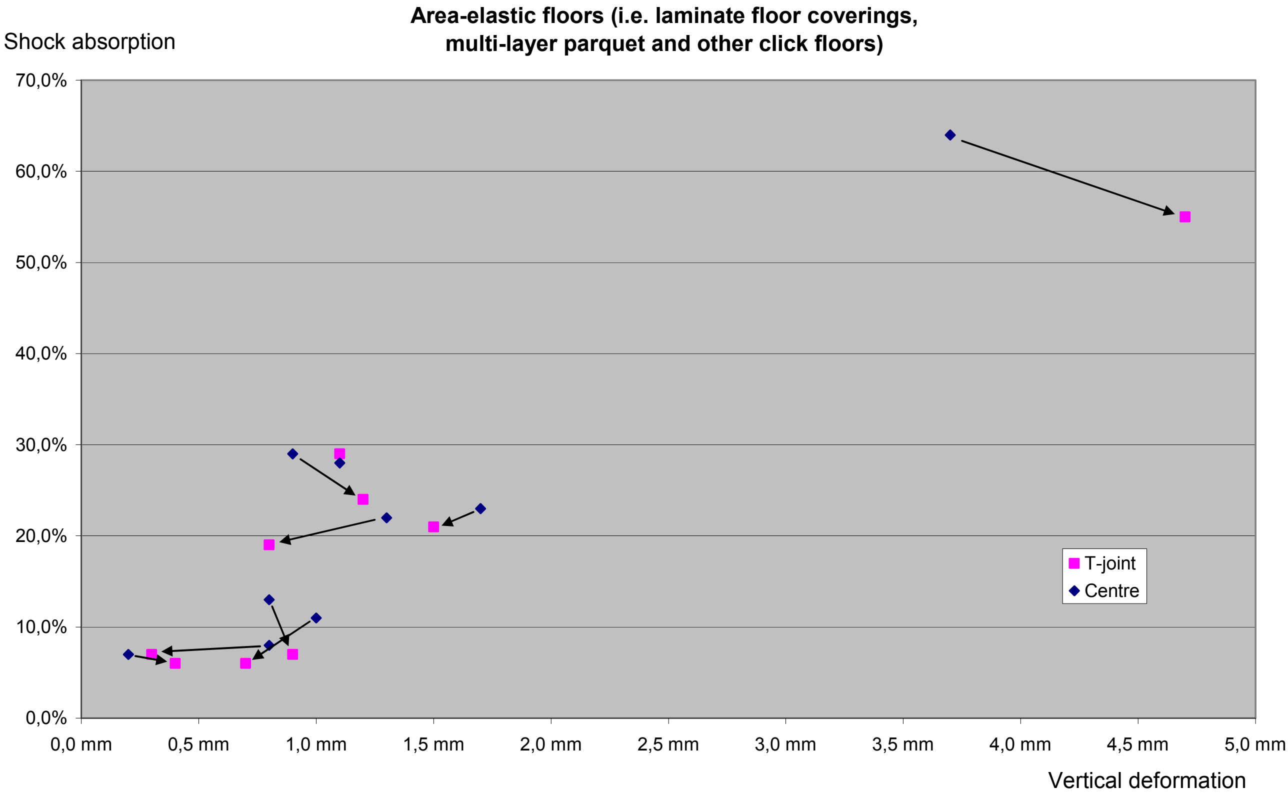

Chart 5 Results, Shock absorption plotted against vertical deformation

5 Conclusions

5.1 Suitability

The results of this study indicate that the two methods are well suited to determine the mechanical comfort of a flooring. However when measuring floors with very little ability to absorb energy and with almost no springiness, the methods are not useful. One reason for this is that the measurement uncertainty becomes higher for lower results. Another reason is naturally that the results will be so low that the resolution of the test equipment will not make it possible to determine useful readings. Therefore the conclusion must be that the method is not suited to discriminate between floor constructions with a shock absorption lower than 4 % and a vertical deformation lower than 0.3 mm. These test methods should preferably be used on floorings claiming enhanced ergonomics, walking comfort, sound-absorption, etc

The way the comfort properties of a floor covering is experienced also seems to be affected by the friction between sole/foot and the floor surface. It might be a good idea to report a value on dynamic coefficient of friction as a complement to these methods.

5.2 Normal Readings

It is probably impossible o declare some kind of standard values for traditional floor coverings on basis of the statistical data of this study. On the other hand, this study shows that most of the floor coverings in public areas in Sweden today have very little springiness. Testing such rigid floor constructions with these methods will not provide any meaningful information..

5.3 Floor Coverings at Skottsundsbacken

Questions have been raised, regarding the possibility to see any differences between the two floor coverings that were used at Skottsundsbackens home for elderly. Material from the same product as in the original floor covering, as well as the replacement floor covering at Skottsundsbacken were tested in this study.

The floor covering that was condemned as having an unsatisfactory springiness by the Swedish Work Environment Authority was a 2.0 mm homogeneous polyvinyl chloride floor covering. The shock absorption for this material was 0.6 % and the vertical deformation was 0.2 mm. The floor covering replacing this was a 1.5 mm homogeneous polyvinyl chloride floor covering with a 2.5 mm polyvinyl chloride foam backing. This material had a shock absorption of 8 % and a vertical deformation of 0.4 mm. This proves that the test methods clearly can distinguish the difference between these two materials.

5.4 Correlation Between Shock Absorption and Vertical Deformation

When studying the graphs it first seems obvious that there is a correlation between shock absorption and vertical deformation regardless of what material is tested. If so, an approximate correlation would be: *vertical deformation = 6.5 × shock absorption* (i.e. a shock absorption of 17 % should result in a vertical deformation of 6.5 × 0.17 = 1.1 mm). However, this could only be seen as a very rough estimation. At a closer look the results indicate that the factor (6.5) varies between approximately 3 and 11.

6 Recommendations

The results of this study clearly indicate that the use of the two European methods EN 14808 and EN 14809 is well suited to describe comfort properties for floor coverings claiming ergonomic/comfort properties. It is therefore recommended that these two methods are used to declare the mechanical comfort properties for these type of floor coverings.

The scope of the two test methods declares that the intended use for the test methods are for sport surfaces. It is therefore recommended that SIS, Swedish Standards Institute start developing an overarching standard for measurement of mechanical comfort on floors. This standard should be suitable for all kind of floors, both in situ and in laboratory. Regarding the test methods, this standard should refer to EN 14808 and EN 14809.

The clinical study at Skottsundsbacken and Lindgården is a very good start. It shows that changing to a softer floor covering results in a significant reduction of pain in feet. Further clinical studies are however needed to fully grasp the impact of softer floor coverings, i.e. floors with higher springiness.

It is highly recommended that the Swedish Work Environment Authority take into account the possibility to quantify the mechanical comfort of floor coverings with regard to EN 14808 and EN 14809. It is desirable that the Swedish Work Environment Authority formulates recommendations for the shock absorption and vertical deformation needed for certain work activities.

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Reference: N2003/5546/ARM

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SS-EN 14808:2005 Surfaces for sports areas – Determination of shock absorption

SS-EN 14809:2005 Surfaces for sports areas – Determination of vertical deformation

SS-EN 14904:2006 Surfaces for sports areas – Indoor surfaces for multi-sports use – Specification

DIN V 18032-2:2001 Sport halls – Halls for gymnastics, games and multi-purpose use – Part 2: Floors for sporting activities; Requirements, testing

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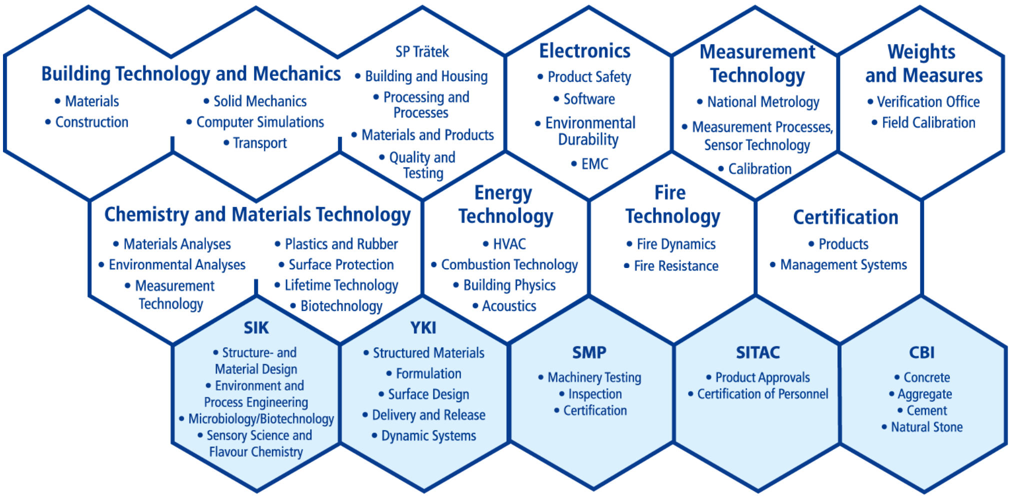

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