SEAMLESS ACOUSTIC CEILINGS
STRUCTURAL OPTIMIATION
WITH POSITVE EFFECT ON ACOUSTIC PROPERTIES

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Key words: seamless acoustic ceilings, sound absorption, innovation

Seamless acoustic ceilings pose a major challenge from many perspectives and especially in terms of acoustic technology. The wishes of builders and architects are generally taken into account by a large number of technical approaches. Usually there are suspended ceilings with subconstruction of metal profiles, seamlessly planked with boards and seamlessly coated. In a compromise between construction technology and acoustics, the substructure is covered with boards suitable for construction. The boards should resolve the contradiction between robustness, processing, load-bearing capacity, safety, fire classification, quality and costs on the one hand and sound absorption on the other. The compromise is often at the expense of the acoustics. Perforated boards made of reflecting material absorb spectrally selectively. Soft fibre insulation boards require a wide, reflective filling on the butt joints for even surfaces and thus limit the absorption to only medium values.
A new technology is presented here, where the solution includes special boards in combination with acoustically adapted plasters, broadband, uniform sound absorption with a very flat frequency response can be reproduced in stages and - above all - can be achieved on construction sites. The solution also offers builders and architects excellent surface quality with simplified assembly.

1. REQUIREMENTS

Customised room acoustics are required in all spaces used for communicating, listening to and playing music, and working – as well as in spaces in which we seek relaxation and revival. It is proven and generally acknowledged that good room acoustics designed specifically for the intended purpose for which a space is to be used create calm, minimise noise, and promote speech intelligibility – creating the perfect conditions for maintaining and increasing efficiency whilst at work. The health protection benefits of noise reduction and the avoidance of physical strain as a result of stress are particularly worthy of note.
Sound-absorbent ceiling systems which affect room acoustics are often used in this context. Seamless systems which help to achieve the desired high-quality architectural impression and open up new design possibilities are particularly effective. Seamless ceilings hide technical details (joints, slits, holes, embossing) to the benefit of overall visual impact, turning a suspended ceiling into an absorbing ceiling, along with its supporting elements.

This places seamless ceilings in something of a dilemma, because the essential additional function “sound absorption” is “only” audible but not visible. However, this “dilemma” can always be turned into a valuable quality feature if seamless ceilings offer a reliable solution from the construction point of view plus acoustics without compromising the overall design with their construction details, as can be seen in Figure 1.

Figure 1 - Unilever Headquarters, ID Jakarta (photo: Architenthis Asia Pte Ltd., Singapore)

Seamless ceilings have to meet very demanding requirements in terms of evenness. This is a particular challenge at screwing points and joints, as these elements must not be visible in the overall design. There is potential for conflict here, because the need for even and smooth surfaces often requires structural solutions that can lead to technical and visual difficulties. There is often conflict between looking good and finding a top-quality acoustic balance.

2. STANDARD TYPE OF CONSTRUCTION

The essential components of a seamless acoustic ceiling of standard construction are explained below using the example of a perforated gypsum board ceiling, see Figure 2:
The ***load-bearing construction*** with fixings, hangers, joints, and profiles creating a supporting frame – responsible for resistance, safety, and evenness.
The ***acoustic board***, usually made from engineered wood, gypsum, or metal sheet and featuring perforated holes, slits, and drilled holes with the addition of mounting profiles which are screwed into place and then filled and levelled – significant for integrity, stability, evenness, and critical to sound absorption through the hole pattern. Perforation is usually limited to just 20 % of the total area; in extreme cases it can be up to 27 %, reaching the limits of strength and stability then.
Monolithic boards, like artificial mineral or natural fibre material and mineral wet-felt boards, need to be of relatively high density in order to provide the necessary resistance and stability, but they are then often too dense for maximum absorption.

Figure 2- Seamless acoustic ceiling made from perforated gypsum boards, nonwoven fabric facing, with spray plaster (source: Sto)

Joint filler is necessary to level out unevenness, board joints and to create a smooth and even surface. As standard those fine fillers are airtight, sound absorption in the filled area is reduced to almost zero, with decreasing impact on the resulting absorption of the ceiling as a whole.
Joints on mineral fibre boards are filled airtight up to 250 mm wide, with a similarly declining effect. The filler turns rigid when it dries, making it very difficult to sand level, in particular when working with fibre boards that are springy to the touch and not very pressure resistant. In sharp glancing light, joints and screwing points are clearly visible in the form of cast shadows. The surface of the ceiling only looks perfect in diffuse light, see Figure 3.

Figure 3 - Seamless ceiling of mineral fibre boards with nonwoven fabric facing, joints and screwing points filled and levelled, sanded, with spray plaster – view in glancing light (photo: Sto)

The ***facing of the surface*** of the boards with the glued nonwoven fibre and coating is responsible for sound absorption, together with the optional cavity damping. Its acoustic airflow resistance should be calculated so that the system is ideally equipped for broadband sound absorption to a high level.
The coating plaster is highly demanding to apply by hand, because surface quality is the crucial criterion for building owners and architects. Against this background comes the challenge of avoiding dust deposits in and around punch holes, which are caused due to differences in pressure and subsequent airflow between the room and the ceiling cavity through the ceiling. Figure 4 shows the resulting impairment of visual impact and makes clear how much time and money refurbishment would incur.

Figure 4 - Dust deposits and hole markings on a seamless acoustic ceiling made from perforated gypsum boards, nonwoven fabric facing, with spray plaster (photo: Sto)

To prevent dust deposits of this nature, the back of the board is fitted with an airtight covering. An airtight PE-foil membrane is often used for perforated boards, an airtight nonwoven fabric for fibre boards, and a thick layer paint coat for wet-felt boards. The decreasing impact on sound absorption is demonstrable, not only in the single number value but also in particular in the selective absorption spectrum, see Figure 5.

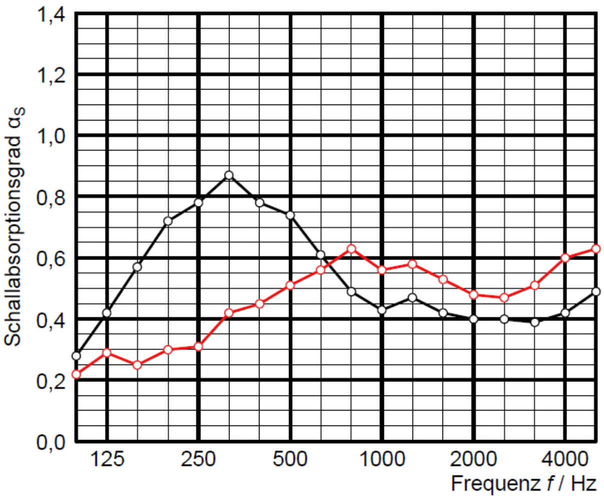

Figure 5 - Sound absorption according to EN ISO 354 type E-200, perforated gypsum board hole pattern Qg 12 25 23 % perforation, nonwoven fabric facing, with spray plaster
with PE foil-membrane: α_w = 0.55 (*L*) (red)
without membrane: α_w = 0.45 (*LM*) (black)
(measurement: Sto)

The effect is particularly marked when working with monolithic boards which have an airtight covering on the rear side in order to avoid marks on the surface caused by joints and screwing points which have been filled and smoothed airtight, see Figure 6.

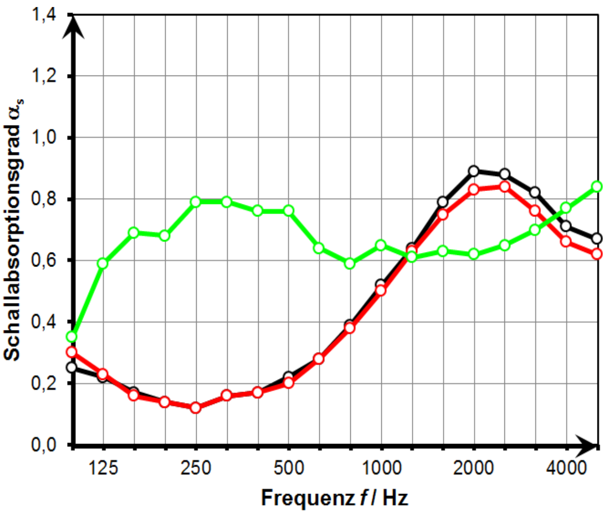

Figure 6 - Sound absorption according to EN ISO 354 type E-200
15 mm expanded glass granulate board with spray plaster
rear side open: α_w = 0.65 (*L*) (green);
rear side airtight: α_w = 0.30 (*H*) (red, black)
(measurement: Sto)

It becomes clear that the airtight coating on the rear side of the boards significantly reduces low-frequency absorption, because the $\lambda/4$ absorber-effect – absorbing material in a certain distance to a sound reflecting substrate - cannot work. In addition, optional cavity damping will demonstrate very little effect if the back of the board is airtight. Only the porous board has any effect, and even this is primarily at medium and high frequencies, as shown in the results (see Figures 5 and 6).
Suitability for room acoustics is restricted here and balancing measures are required when planning audio spaces. These include bass absorbers, for example, in order to achieve the aim of a harmonious and balanced frequency response of the reverberation time. There seems to be a dilemma in that smooth surfaces of the highest visual quality that keep their good looks over time and are also capable of broadband, harmonious, and high sound absorption seem virtually impossible to achieve using porous and perforated boards. But this dilemma has now been resolved.

3. THE PROPOSED SOLUTION

From the prerequisites, requirements, and limiting conditions described above we can derive a number of specifications for optimising the design and construction of seamless ceilings if we are defining positive effects for acoustic properties as our overriding aim. This was the challenge tackled in a comprehensive development project that involved careful measurements of acoustic and technical parameters.

- All technical details of the ceiling system that would reduce sound absorption must be avoided.
- A high level of sound absorption alone is not sufficient as an objective; sound absorption as broadband as possible must be achieved by “activating” all the absorber effects.
- It would be ideal to have a number of different versions facilitating technical solutions from low to high and even very high single-number absorption values and meeting a wide range of requirements relating to room acoustics in spaces used for a variety of different purposes.
- Protection against local soiling and “joint marking” must be assured.
- Surface quality must be very good: smooth and level, with as few cast shadows as possible in glancing light caused by local filled spots.

The project was implemented using boards made from expanded glass granulate with a broadly isotropic structure, with nonwoven fabric facing, because unlike perforated boards made from timber, gypsum, or metal, these boards are absorbent all over. The boards are lightweight and stable, so that the grid dimension of the sub-construction is load bearing and can be clad very evenly.
However, the boards do not require additional screw fixing, so screwing points and a local filler and levelling coat are not needed. The acoustic panels are glued under a load-bearing single layer construction as a patented method.
For the purpose of bonding, each board edge must be backed with a supporting profile glued with the board in order to create stability. The stability of the bonding board-adhesive-sub-construction has proven to be high enough to be able to do without additional bonding of the edges of the board, as would otherwise be necessary when working with screw fixed boards made from expanded glass granulate or other porous material.
The boards can be aligned three-dimensionally with very high precision in the adhesive bed, producing extremely smooth surfaces with butt joints in the range of 1/10 mm even without a coating, much more precise than can be achieved with other boards or mechanical fixing methods. By means of a special nozzle and an adhesive with very high initial tack very exact, secure and reproducible bonding is achieved.
As the board joints are no longer screw fixed to the subconstruction and the joints no longer must be filled and smoothed, there are no longer any airtight surfaces alongside the porous absorbing board.

The back of the board must be open and not airtight in order to absorb sound at low frequencies, the $\lambda/4$ absorber-effect – absorbing material in a certain distance to a sound reflecting substrate – can take effect. The desired acoustic tuning of the overall system comprising the ceiling cavity, the acoustic board, and the coating is achieved by using different types of boards in combination with a selection of coating systems. The type of application selected for the coating can also influence acoustic adjustment.
From the point of view of acoustics, tuning the individual components (cavity, board, coating) does not appear to be conclusive initially. Other materials, in particular fibre insulating materials, exhibit more or less constant airflow resistance over their entire cross section. Even the very thin finishing coat is very porous.
A different approach was selected for this system. As the carrier board is open and the finishing coat is much denser relative to it, the absolute value and sound absorption spectrum can be influenced in a very specific way, as was verified by tests carried out in laboratory and reverberation chamber.
Protection against joint markings was tested on our own dedicated test stand under forced stress with nano dust produced specifically for this purpose. The absence of an airtight filler on the surface means that markings caused by dust deposits are no longer visible. By extension, the sound absorption of the entire surface area is maintained, so that the measured values from the laboratory and the reverberation chamber do not have to be reduced by the surface proportion of the reflecting filler and levelling coat.

4. RESULTS

The sound absorption aims outlined above have been largely achieved with the ceiling system under consideration here due to the use of isotropic boards made from bound expanded glass granulate with nonwoven fabric facing on both sides. A distinction can be made between two versions of boards based on how the granulate is bound: with an organic binder or binding through sintering.
Thanks to the particular structure in sintered expanded glass granulate, with the porous surface of the individual particles, firstly sound absorption is very much higher and secondly the rigid structure shifts the maximum of absorption towards lower frequencies compared with organically bound expanded glass granulate boards. By this two versions of boards are available, both of which deliver the same visual result but at acoustical different levels.

The acoustically adapted nonwoven fabric facing of the boards is also a critical factor. The back of the board has been designed to be as open as possible using nonwoven fabric with very low airflow resistance. The nonwoven fabric on the visible side has been adapted to the coating with a covering material that is in paste form but dries porous. The organically bound 19 mm board has an airflow resistance according to EN 29053 of approximately R_S = 920 Pa s/m, compared with the sintered version with approximately R_S = 670 Pa s/m at a thickness of 25 mm (measurements: Sto).
The different coating systems at a thickness of approximately 2 to 3 mm demonstrate a much higher airflow resistance than the board. This results in sound absorption tending to decrease at high frequencies. Compared with boards made from fibre material with very thin spray coatings, this results in what is at first glance apparently a competitive disadvantage around absolutely maximum values. However, in planning practice, experience has shown that the maximum values solely at maximum frequencies are not necessary.
A major acoustic advantage of a coating that is ostensibly too thick on an absorbent board has been confirmed that it results in higher absorption across the entire system at mid-range and very low frequencies, bringing significant benefits for the acoustic application. If the ceiling cavity is then fitted with an additional fibre insulating material 30 mm thick or more (airflow resistance approx. R_S = 5 kPa s/m), the absorption of the ceiling system can be increased still further.

For reproducible and practical complete structures, 19 mm organically bound boards result in airflow resistances of approx. R_S = 2,500 Pa s/m with spray plaster and approx. R_S = 4,000 Pa s/m with trowel plaster. By way of experiment, a coating method was also selected during the development process in which the coating is extremely dense, with a total value of R_S > 5,000 Pa s/m, far exceeding ideal values for acoustics. A very flat frequency response was shown to be the result, with a weighted sound absorption coefficient of just α_w = 0.25. This can be deemed an interesting result without much practical suitability. The sound absorption spectra according to EN ISO 354 from the reverberation chamber for a type E-200 structure are shown in Figure 7.

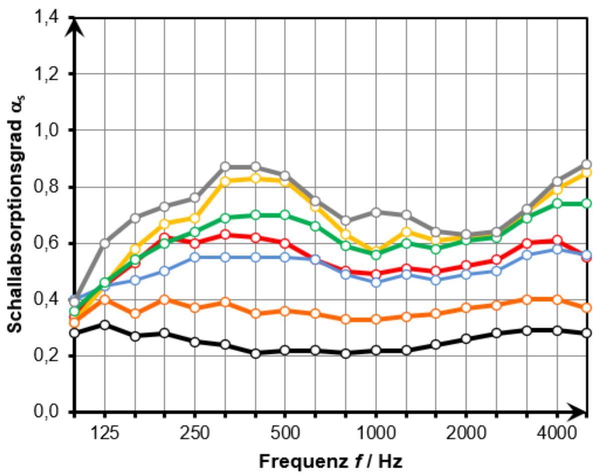

Figure 7 - Sound absorption according to EN ISO 354 type E-200, 19 mm organically bound board, lowest values with trowel plaster, highest values with spray plaster (measurement: Sto).

The weighted sound absorption coefficients for the results in Figure 7 range according to EN ISO 11654 from α_w = 0.25 (black) with trowel plaster up to α_w = 0.70 (*L*) with spray plaster and 30 mm insulant layer (grey).

In a practical complete structure, the following airflow resistances result for sintered 25 mm boards and can be reproduced: approx. R_S = 1;300 Pa s/m with spray plaster and approx. R_S = 2;200 Pa s/m with trowel plaster.
By way of experiment, a coating method was also selected here in which the coating is extremely dense, with a total value of R_S > 3,200 Pa s/m. It was confirmed that the frequency response is very flat even with the sintered board, with a weighted sound absorption coefficient according to EN ISO 11654 of at least α_w = 0.50. The sound absorption spectra according to EN ISO 354 from the reverberation chamber for a type E-200 structure are shown in Figure 8.

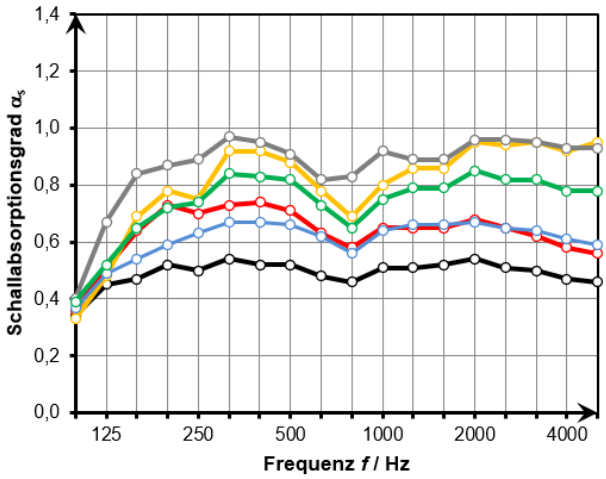

Figure 8 - Sound absorption according to EN ISO 354 type E-200, 25 mm sintered board, lowest values with trowel plaster, highest values with spray plaster (measurement: Sto).

The weighted sound absorption coefficients for the results in Figure 8 range from α_w = 0.50 (black) with trowel plaster up to α_w = 0.95 with spray plaster including 30 mm insulant layer (grey).

5. SUMMARY

Compared with other materials and systems, the specifically controlled combination of expanded glass granulate board, cavity and coating can achieve very high acoustic suitability for many rooms acoustic applications. Other typical disadvantages including selective absorption, cast shadows in glancing light, and imperfect surfaces are avoided.
Seamless ceilings designed and applied as outlined in this document under the technical boundary conditions described can achieve high absorption values with a very flat and harmonious frequency response. The largest range of values from α_w = 0.55 (*L*) up to α_w = 0.95 can be achieved specifically with the combination of board type and coating version in a way that is structurally suitable and reproducible.
The advantage of boards made from expanded glass granulate is worthy of note here, as they support structurally suitable and straightforward application which is also very precise.
The patented bonding method facilitates very exact alignment and levelling of the boards to create a very smooth and level surface. This is the key technology for the solution described in this document.