ram reports in applied measurement

Comparative long-term measurements on buildings made of normal concrete and concrete made of reprocessed aggregate

Gerhard Koster,
Marcus Rühl

Massivbau,
Technische Universität
Darmstadt

Figure 1: Test building

Preface

The amount of building rubble in Germany is steadily increasing. And this is a high-grade raw material, which it is possible to reuse as an aggregate for making concrete. In the course of a building project sponsored by the Federal Ministry of Eduction, Science, Research and Technology (BMBF) and the industry, two structurally identical buildings were built from conventional concrete and from recycling concrete. The article describes the design and implementation of a measuring device which makes it possible to furnish evidence about the long-term behavior of both buildings.

Introduction

As a consequence of new building, conversion, retreat working, repair and maintenance, large quantities of building waste are produced every year. Of these quantities, after earth excavation, building rubble makes up the largest proportion, quantity-wise. Considerable quantities of this building rubble are already being used in highway engineering, road construction and earthworks. These areas of application for reprocessed mineral building rubble materials have their limits, however, with regard to their absorption capacity. Furthermore, in addition to the mineral building rubble materials, industrial byproducts are also used in these areas of application. But the amount of building demolition will visibly increase over the next few years. In the German Recycling and Waste Disposal Law (Kreislaufwirtschafts- und Abfallgesetz) of 27th September 1994, the legislator required the best possible use to be made of the volume of residual materials. A possible area of application, in which to comply with the demand for the best possible utilization, is the use of reprocessed mineral building rubble materials as aggregate materials for the production of concrete.

According to the Federal Statistical Office (Statistisches Bundesamt), solid waste production in Germany in 1993 amounted to 337 million Mg (1 Mg = 1 t) compared to 1990, this means a drop of 37 million Mg. Building waste, with 132 million Mg, took up about 40 % of the total waste quantity.

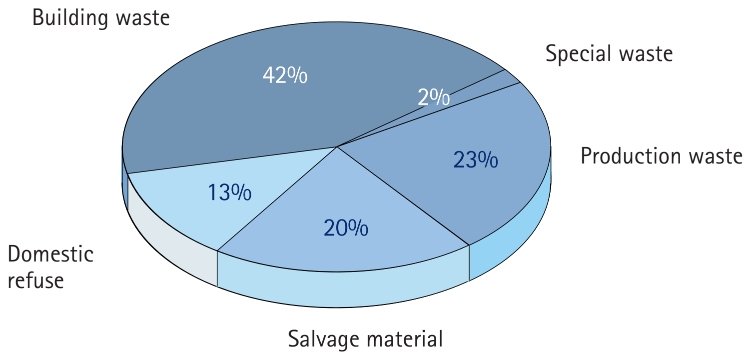


Figure 2: Waste composition

The pressure on the one hand to reuse more demolition material and the uncertainty on the other hand, which from the technical viewpoint is still an obstacle to the general use of this type of material, has lead the German Committee for Reinforced Concrete (DafStb) to initiate a research project, which should result in the general regulation of the use of demolition material for producing concrete for structures in compliance with DIN 1045. This project, which was set up on the 1st May 1996, under the title: "Building material recycling in solid construction", was sponsored approximately 50-50 by the BMBF and from industry funds. Research work into the basics should clarify the conditions under which the mineral residual construction materials that are produced by the demolition of buildings can be utilized to the greatest extent in the construction of new buildings.

Project description

On an industrial site that is no longer used, the restructured Bürgerparkviertel in Darmstadt, demolition, renovation and new construction have produced a residential and service center of a more modern stamp. As a part of this restructuring, there is a building that has been made from concrete with recycled aggregate. An integrated concrete volume of about 500 m^3 is involved. Building inspector approval was obtained for the use of the concrete with recycled aggregate.

The new building project "Vilbeler Weg" covers three adjacent administration buildings, each with a basement, a ground floor and four upper storeys and an adjoining multi-storey car park with seven parking levels behind the administration buildings. The unusual feature of this building project is that two of the buildings have been designed as mirror images. This mirror image not only relates to the architectural design, but also to the static structural design of the supporting framework. The planned implementation for the bearing building components was reinforced concrete constructions.

Because the static structural design of the buildings was identical, it was proposed to realize one of the properties with conventional concrete with a dense aggregate and for the other property, to use a concrete comprising 100 % recycled aggregate made of reprocessed broken concrete. The two buildings that are identical, but which have been made with different types of concrete, can now be observed to detect any differences between the supporting framework deformations that occur now that the buildings are in use, under the same constraints.

Measurement objective

Compared to normal concrete, concrete made from recycled aggregate has slightly different deformation properties. These differences relate in particular to the modulus of elasticity and the time-dependent deformation behavior, such as shrinking and creeping. This is why it cannot be ruled out with long-term load introduction that greater deformations may appear at the load-bearing members.

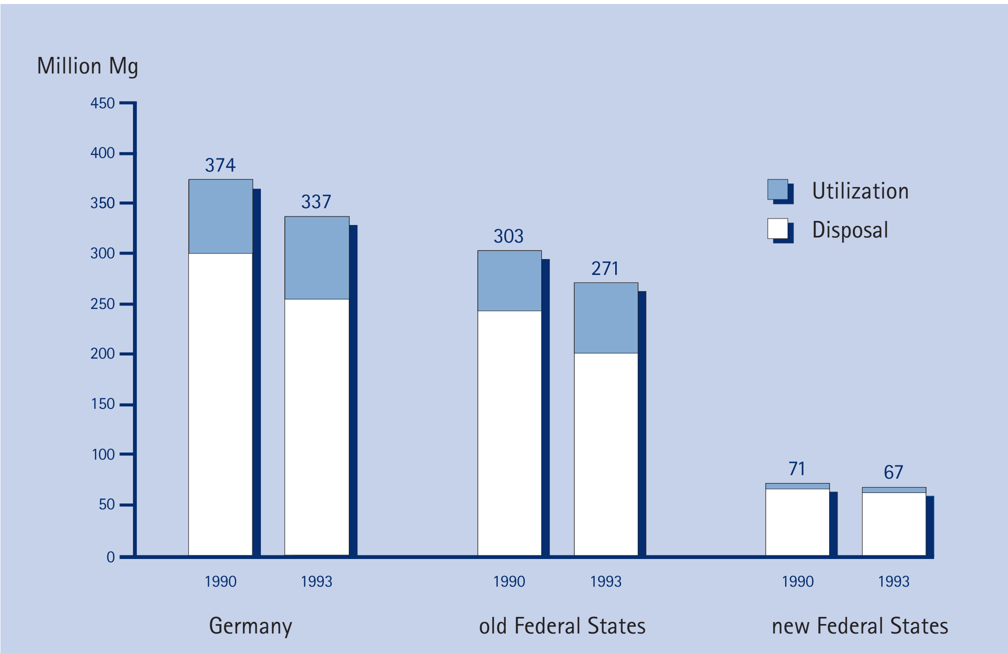


Figure 3: Waste quantities

Concrete	with a dense aggregate	with recycled aggregate
Apparent density of green concrete [kg/dm³]	2.40	2.28
Compressive strength of concrete [N/mm²]	49.1	49.6
Tensile splitting strength of concrete [N/mm²]	3.6	2.7
Static modulus of elasticity [N/mm²]	34,000	22,300

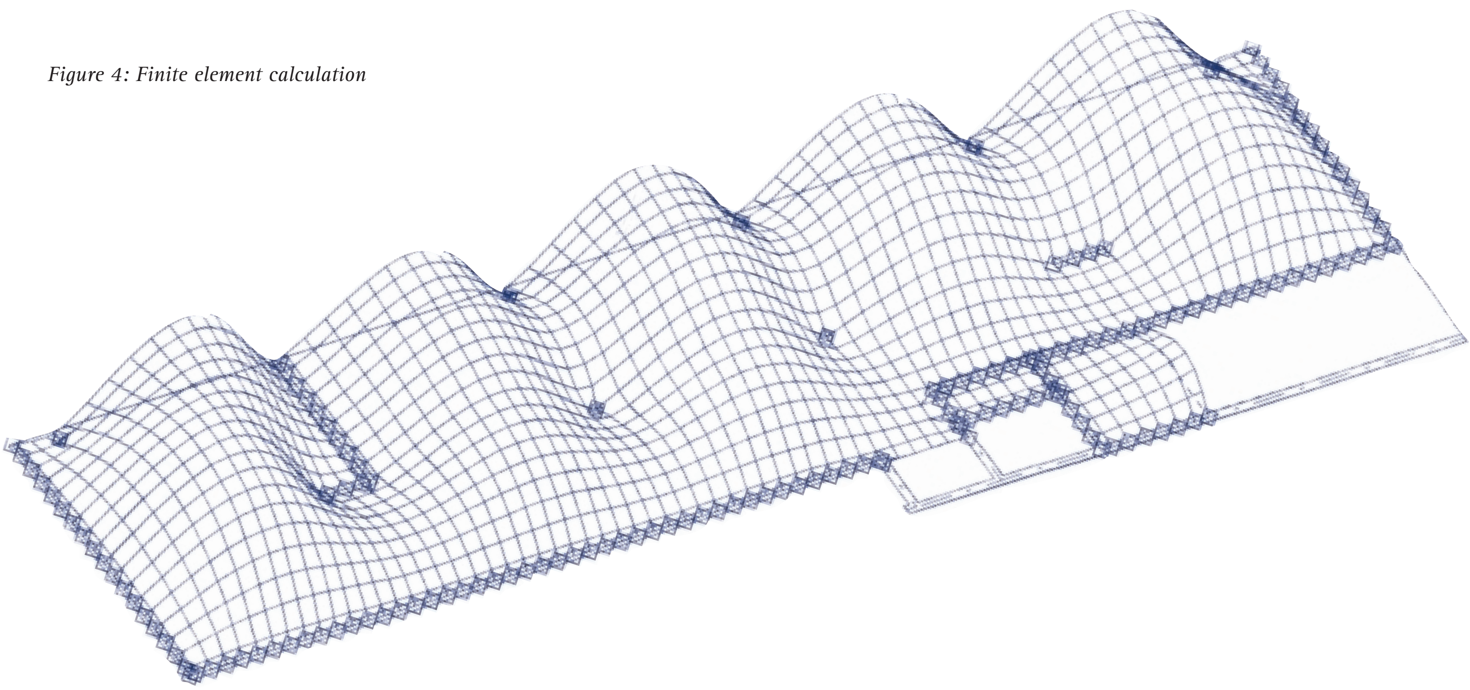
Table 1: Concrete properties

Properties of the concretes that were used

The dissimilarity of the aggregates used when making the concretes has produced different properties in the finished concrete. Important variables in the evaluation of concrete include the maximum detectable compressive and tensile strength (aged 28 days) and the value of the modulus of elasticity, which furnishes evidence about the deformation behavior of the concrete. The major properties of the concretes are compared in **Table 1**.

As can be seen from Table 1, the recycled aggregate made of broken concrete that was used did not affect the level of compressive strength of the concrete that was made from it. This is justified by the fact that the attainable compressive strength of a concrete normally depends on the resistance of the hardened cement paste matrix surrounding the aggregate. The tensile strength of the concrete with the recycled aggregate can decrease compared to that of the concrete with a dense aggregate, as during the production process from demolition material to recycled aggregate , mechanical influences can result in structural changes (fissures, cracks) in the material. The value of the modulus of elasticity is greatly affected by the apparent density of the aggregate used. If an aggregate made of reprocessed broken concrete is used, the new concrete will have an increased proportion of hardened cement paste. This has a lower apparent density than the normal dense aggregate. As this used hardened cement paste becomes aggregate in the new concrete, the concrete that is made from it has a lower apparent density than a concrete made from a normal dense aggregate. The greater proportion of softer components in the new concrete reduces the modulus of elasticity, which, when a building component made of concrete with recycled aggregate is loaded, can lead to increased deformations.

Figure 4: Finite element calculation



This is why it may be advisable, under certain circumstances to check the deformation behavior when using concrete with recycled aggregate [1].

Implementing the measuring device

The range of measuring instruments required to measure the relevant measured quantities and their interconnection, is detailed below. Because of the different material properties of the recycling concrete, the following measured quantities are of interest [2].

Deflection

By using a finite element calculation, first the points in the supporting system are determined that will show maximum deflection at the load to be expected. The ceilings were designed as slabs, whose load is discharged via pillars and walls.

The place at which maximum deflections occur as a result of a load, was determined with the aid of the finite element calculation, taking into consideration the load and the characteristic values of the building material **(Figure 4)**. This place is located on the free edge in the middle of the ceiling.

At the point where the calculation determined that maximum deformation is to be expected, a horizontal, torsionally rigid section was attached between the supports. An inductive displacement transducer of type W5 was attached in the center of the section, to record the deflection of the ceiling.

Concrete strain

The place where there is most deflection, is also the place where there is the most associated concrete strain. The concrete strain is measured with W1 inductive displacement transducers over a measured length of 100 mm. Inductive displacement transducers were used, as even during the construction phase, concrete strain and deflection were monitored by mechanical dial gages, see **Figure 5**.

Shrinkage deformation and creep deformation

Special transducers were produced for this and were embedded in the concrete. Between two anchor plates, there is a strain element made of a steel tube, to which four strain gages of type 3/120 XY11 are attached. The S.G.s were connected as a full bridge. The cables are routed inside the steel tube, which was later encapsulated. An application of PU120 served as the first coating to protect against moisture. A second coating was of AK22. Then an aluminum foil was attached as a diffusion barrier and sealed with PU120. The PVC tubing cover that was fixed over this and sealed with silicon, fulfils two functions. Firstly it serves as a general protection during embedding in concrete and secondly, it ensures that deformations are only introduced to the measuring element at the anchor plates. [3], see **Figure 6**.

Temperature

Concrete has a temperature coefficient of approx. 1×10^{-5} /K. The deformations of the concrete caused by load, are overlaid by deformations caused by the effects of temperature. In order to be able to assign these, the temperature of the concrete was also recorded at the relevant measuring points. Thermocouples proved to be most reliable here. The soldering points of the thermocouples were given several coats of PU120 and were embedded in concrete as well, or cemented in place by X60 in the concrete surface in the immediate vicinity

Figure 5: Measuring points for deformation and strain

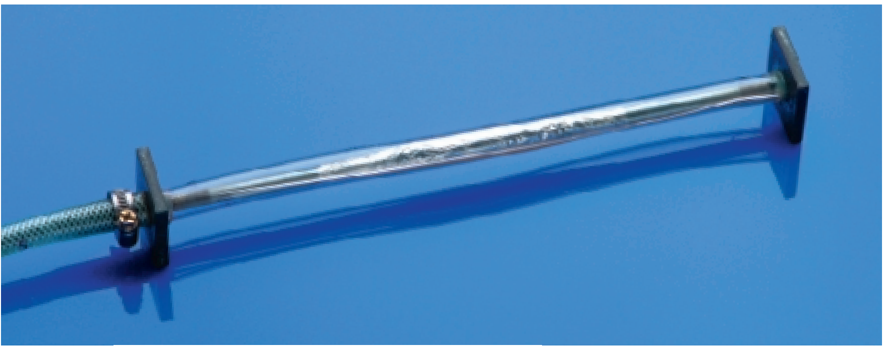


Figure 6: Strain transducer

Figure 7: Instrumentation in the measuring room

of the displacement transducers. The measuring point for the ambient temperature is located on the north side of a parking level stairway structure to protect against direct sunlight. For comparison, a further temperature measuring point was attached to the front of the building behind a façade cover. Commercially available Pt 100 temperature sensors in splash-proof casings were used here.

Instrumentation

Because of the distance between the two measurement objects, there are several alternatives for instrumentation. This also determined the choice of measuring instrument to be used. A possible concept would be setting up a central measuring station, from which the measurement cables branch out to the transducers in the two buildings. A further option is to set up two independent measuring devices. A Spider 8 from HBM is the proposed measuring instrument for this, as all the requisite connection options relating to the transducers to be used are available. With this variant, there are eight measuring points per building. These measuring points are listed in **Table 2**.

Variant two has the advantage that you can keep the measurement cables short. Using measurement cables to cross great distances is expensive and there may be problems in laying the cables. Laying the measurement cables parallel to power cables is to be avoided because of induced interference. This is why using the existing interior wiring cable rack is ruled out.

Independent measuring devices never work syncronously without special arrangements. When the required measuring intervals are in minutes, this is only of secondary importance. However, much expenditure is required to bring the measurement data together for evaluation. Which is why it was deemed desirable to operate both measuring devices centrally from one computer. As the Spider 8 uses a serial interface, this plan was realized. A direct link from the PC to the Spider 8 by RS 232 was ruled out, however, as the requisite cable lengths are outside the specification. To solve this problem, there now exist numerous commercially available methods, such as hard-wired systems or methods that use fiber optics or radio signals.

	Building 1	Spider 1		Building 3	Spider 2
No.	**Meas. pt.**	**Type**	**No.**	**Meas. pt.**	**Type**
1	Wall 1X	S.G.	1	Wall 3X	S.G.
2	Wall 1Y	S.G.	2	Wall 3Y	S.G.
3	Defl 1	Disp	3	Defl 3	Disp
4	Strain 11	Disp	4	Strain 31	Disp
5	Strain 12	Disp	5	Strain 32	Disp
6	T_Wall 1	Therm. J	6	T_Wall 3	Therm.J
7	T_Floor 1	Therm. J	7	T_Floor 3	Therm.J
8	T_Acqu.	Pt 100	8	T_Outside	Pt 100

Table 2: Measuring point plan

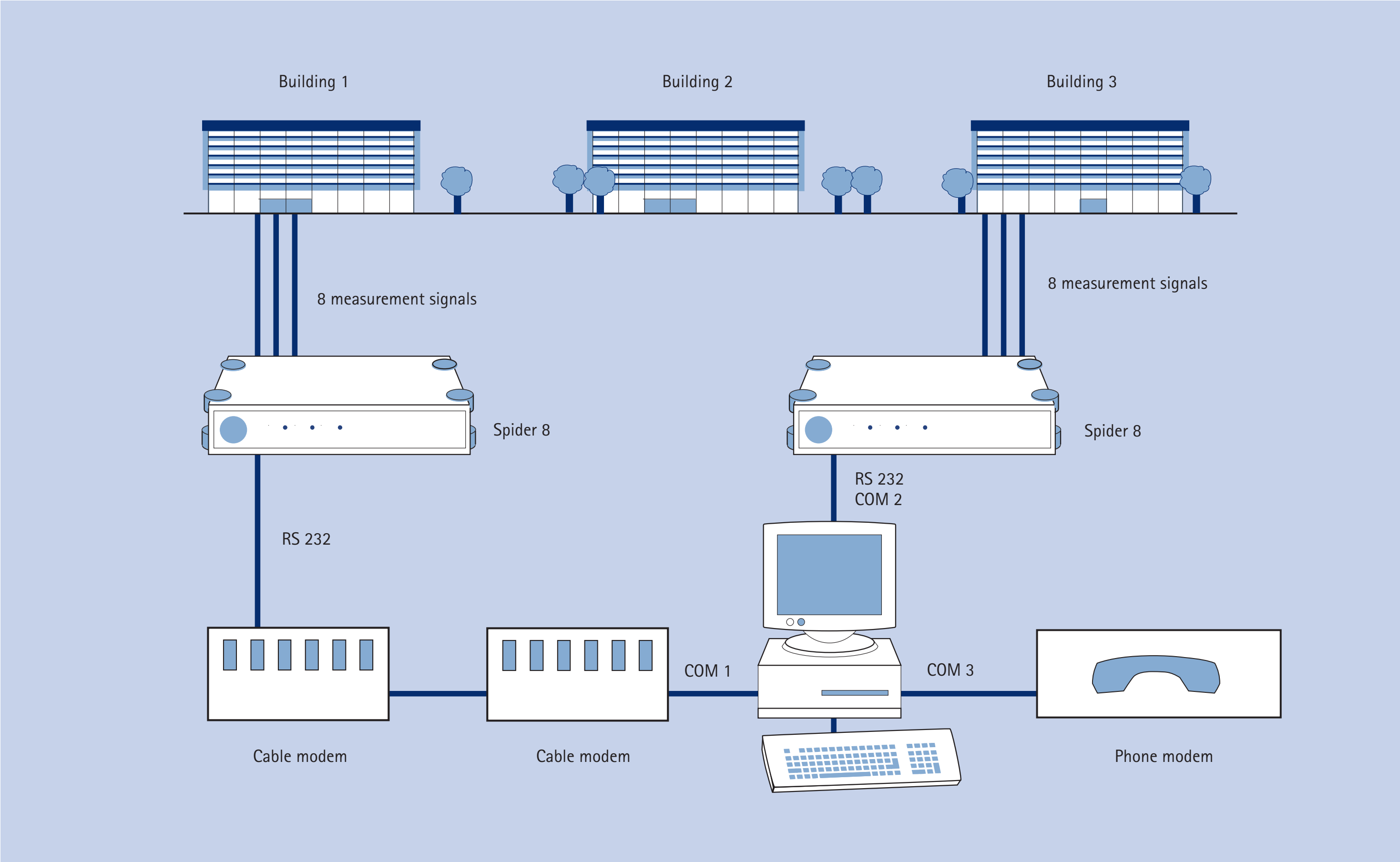


Figure 8: Circuit diagram for the full measurement system implemented in the buildings

There is another project where SC 232 / 422 interface converters from HBM have already been successfully used to carry out a level conversion to RS 422, thus allowing cable lengths of up to 1.2 km [4].

In the present case, cable modems were used that formerly served as a link to a large-scale data processing plant. **Figure 8** shows the circuit diagram for the full measurement system implemented in the buildings.

The measuring station in the building with concrete made of recycled aggregate can be seen in **Figure 7**. In the upper part of the diagram, you can see the Spider 8 with power pack, below this on the right is a cable modem, as a link to the measuring station in the building made of concrete with naturally dense aggregate, where the PC is also located. All the measurement cables are in a terminal box, in the bottom left of the diagram, connected with the Spider 8 connection cables.

Operating the measuring device

To operate the Spider 8, you need suitable software. The MW software developed by the Measurement Technology department of the Institute for Solid Construction (Institut für Massivbau) is used for this purpose. It is a standard data acquisition package that provides device drivers for numerous HBM measuring instruments. The program runs under the DOS operating system. This has the advantage that you only need a simple computer to run it. The measured values are saved on the hard disk of the computer during acquisition. If there is a power failure, all the measured values up to this time are retained. Once the power supply is restored, the computer starts up again and acquisition can be started automatically (by batch). This means that consuming arrangements, such as would be necessary with Windows 95, are not required.

The measurement data can be evaluated with standard software, as there are export interfaces available for numerous data formats (ASCII, catman®, dBase, Dia/Diadem, EXCEL, Lotus, MatLab, Quattro). There is an import filter available for EXCEL (5.0, 95, 97, 2000), which can be used to directly read in MW measurement data.

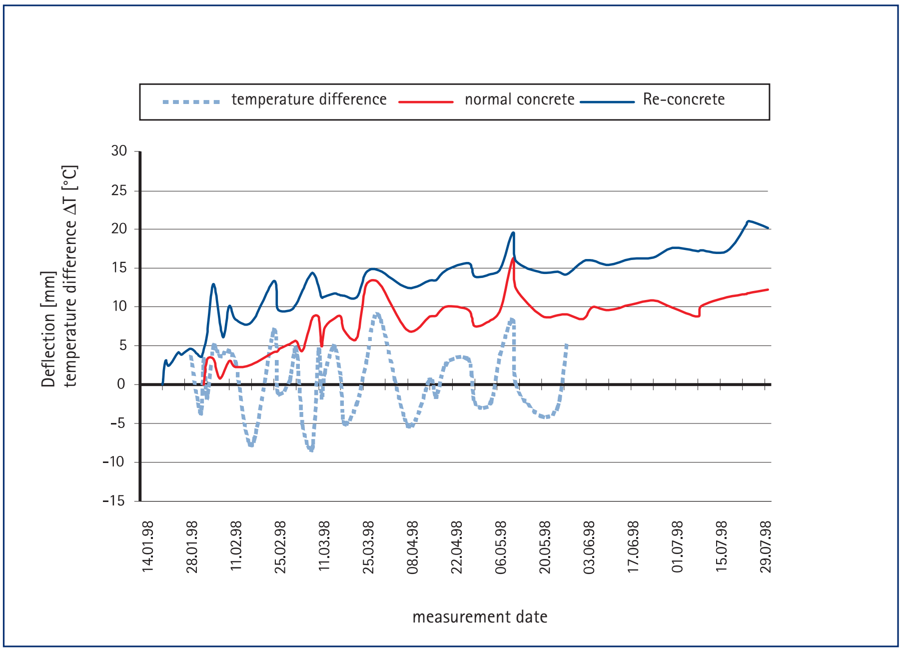


Figure 9: Comparison of the deflections of the ceilings made of conventional concrete, the ceiling made of concrete with a recycled aggregate

Measurement results

The investigations are designed in such a way that the detected measured values provide comparative evidence about the long-term behavior of supporting systems made of concrete with recycled aggregate and supporting systems made of concrete with a dense aggregate. During the construction phase, deflection measurements were carried out manually on the ceiling made of concrete with recycled aggregate and on the ceiling made of concrete with a dense aggregate. As an example, the diagram below shows the deflections of the ceilings in relation to the temperature over a short period. It can clearly be seen that compared to the ceiling made of conventional concrete, the ceiling made of concrete with a recycled aggregate has greater deflections. The slightly changed deformation behavior can be put down to somewhat lower modulus of elasticity of the concrete with recycled aggregate.

Conclusion

The results of the research project "Building material recycling in solid construction" (Baustoffkreislauf im Massivbau) have resulted in the "Concrete with recycled aggregate" (Beton mit rezykliertem Zuschlag) guideline, to regulate the application of this new building material. If concrete is made in accordance with this guideline, the equivalence of a concrete with recycled aggregate to a concrete with a natural dense aggregate is assumed under DIN 1045. The long-term behavior of the supporting frameworks of the demonstration building project cited above that were made with different concretes will be monitored and assessed by ongoing investigations. The investigations thus serve to confirm the required equivalence of the versions. The positive experiences that have been gained from the "Vilbeler Weg" building project from the use of concrete with recycled aggregate, have lead to the development of another extraordinary building in the redesigned Bürgerparkviertel.

In the immediate vicinity of the "Vilbeler Weg" project, the design of the Austrian artist Friedensreich Hundertwasser for an apartment building, the so-called "Waldspirale" (woodland spiral) has been implemented in concrete made of reprocessed used concrete (total volume of concrete about 12,000 m^3) [5]. In the case of this extraordinary building project, concrete with recycled aggregate won through against versions with conventional concrete when it came to awarding contracts. This shows that the new building material is a marketable product with future prospects.

References

[1] Rühl, M.: The production and the properties of concrete using recycled aggregate; Darmstadt Solid Construction Seminar, Volume 18, Darmstadt 1997

[2] Garg, A.: Implementing a measurement system to determine the deformations in a building made of concrete using reprocessed broken concrete; Master's thesis at the Institute for Solid Construction, No. D 006/98 August 1998

[3] Twelmeier, H.; Schneefuss, J.: Summary and appraisal of the method of measurement for determining the stress in reinforced concrete components. German Reinforced Concrete Committee; Berlin 1982

[4] Koster G.: Vibration measurements with acceleration transducers on natural draught cooling towers during demolition blasting; MTB 31 (1995) H.2, pp 25-28

[5] Bathe, K.: Hundertwasser's last building – Darmstadt's "Waldspirale", Hottinger Hotline Edition 1/00

[6] Spider 8: Digital measurement electronics from HBM