Tomorrow's Precast Component Industry – Part 3/8

Hybrid structures – successfully combining differing materials – wood, concrete, steel

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Joining differing materials together to create new composite construction materials is one way of fulfilling today's requirements concerning the energy, sustainability and, at the same time, cost-effectiveness of a construction method. Suitably combining differing construction materials assumes an important function particularly from the aspect of a construction component's multifunctional usage [1]. Each of the materials has corresponding advantages in relation to load-bearing capacity, energetic use, sustainability etc. This means that the challenge in future will be to combine materials in order to exploit this material combination to the maximum advantage possible. Successful applications have already been made with steel and concrete that absorb great stresses with each material. Material combinations can also solve problems in other instances.

To take but one example, a web plate can make large openings within ribs possible so that pipelines can be conducted through them. High load-bearing resistance can then be attained in conjunction with prestressed reinforcement.

Wooden structures offer great advantages e.g. when energy-related issues are taken into account. Such matters can be solved optimally in conjunction with concrete construction components. It is crucial, however, to take care with the timing and assembly of both materials. Wood must be protected from the high moisture linked with concrete in its fresh state. This will only succeed if the individual components are manufactured separately and then later joined together with each other. It also requires new connecting elements whose geometry is designed in an appropriate way to be joined with a liquid grout.

Hybrid structures

The background of the word "hybrid" and its relationship to hybrid constructions can be clarified by looking up its definition according to e.g. Wikipedia [2]. Under hybrid in engineering, a system is generally understood to be two technologies combined together with one another. The prefixed designation "hybrid" then denotes a whole put together from differing types or processes. The special feature is that the elements brought together in such a way already represent solutions in themselves but that their synergies can bring about new, desirable properties.

The magazine Detail [3] formulates the property of a hybrid structure in a similar way:

Prefabricated floor elements with a sandwich cross section

Composite construction work with trapezoidal metal sheeting as non-recoverable formwork

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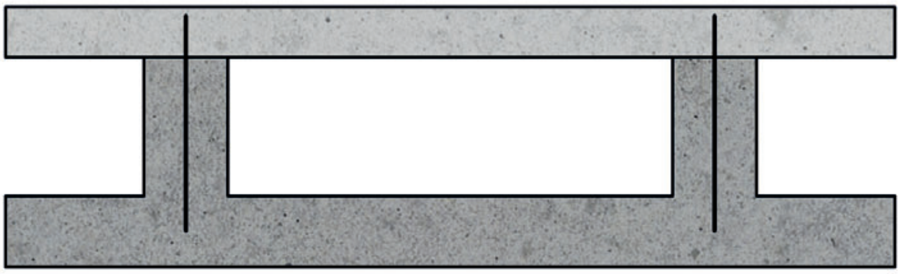
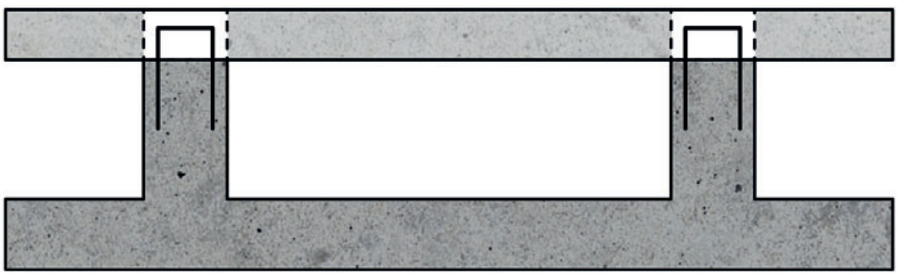
"The combination of the best-suited construction material in each case joined together with traditional building processes using prefabricated elements can optimise processes and will play an increasingly important role in the future as far as energy efficiency is concerned."

The prime aim here is to create new applications from existing proven solutions in order to be able to react with the right material for special requirements. This makes it possible to deliver innovation and develop new construction components or new structures. It means that dealing with differing materials and varying construction shapes enables new territory to be taken and solutions to be found in combination with these substances. Engaging with these subjects is an open road to driving new developments forward.

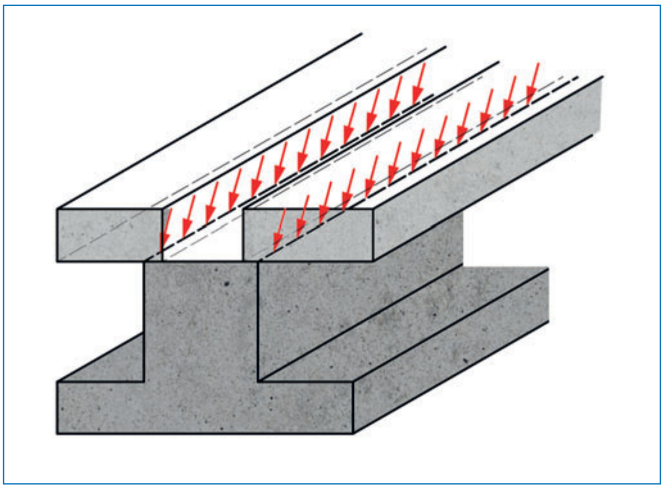
The objective must be to make new developments more effective but, at the same time, more economical than previous solutions. These improvements can be brought to light in many ways, such as more efficient manufacturing, enhanced load-bearing capacity or serviceability, simpler assembly or even accelerating construction processes.



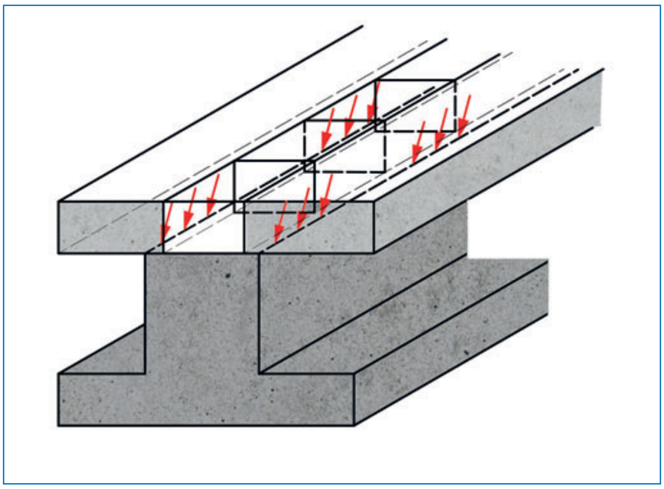
Composite 1 – a continuous bonding between two individual construction components



Composite 2 – punctiform bonding between two individual construction components



Composite 3 – continuous forces along the connecting line of both construction components



Composite 4 – discrete forces within the punctiform connection point

Combination of differing materials

Any combination of differing materials to create a hybrid construction material is always dependent on resolving the connection between both or several different materials. In this context, it is often called a composite construction material. Classic steel reinforced concrete is just such a hybrid construction material. Both materials, concrete and steel, are joined together in a liaison so that the advantages of each material can be exploited. The concrete assumes compressive forces in an ideal manner and the embedded steel is well suited to absorbing tensile forces. This corresponds precisely with the definition of a hybrid material quoted above.

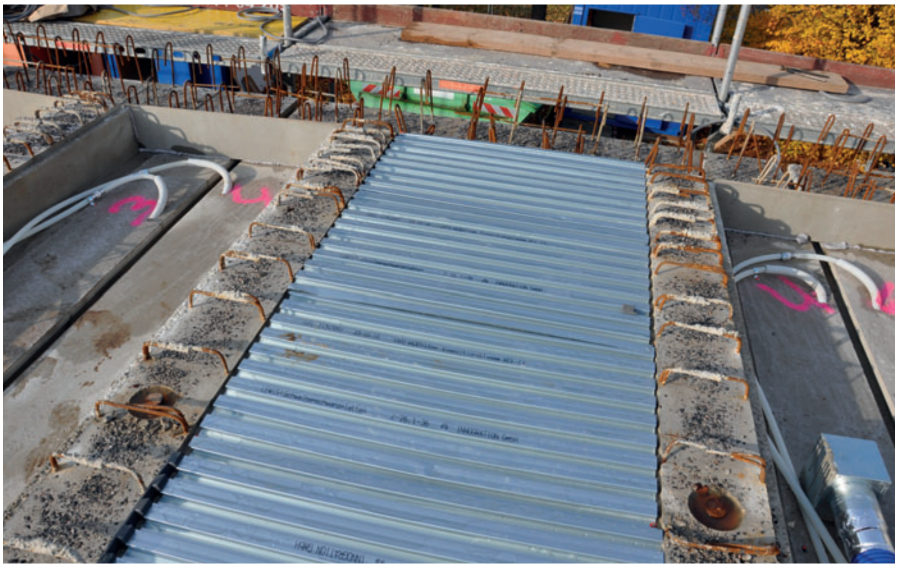
The quality of the connection between both construction materials, or between two construction components made from differing materials, is a decisive factor in a hybrid construction component's effectiveness. In this case, a differentiation is made between continuous bonding on the one hand and punctiform bonding on the other. Continuous bonding can only be achieved by being uniformly embedded. As this option is not always possible, the issue is often avoided by punctiform bonding within a defined interval. The following will describe some applications showing the one or the other bonding methods.

Hybrid construction components made from concrete in combination with concrete

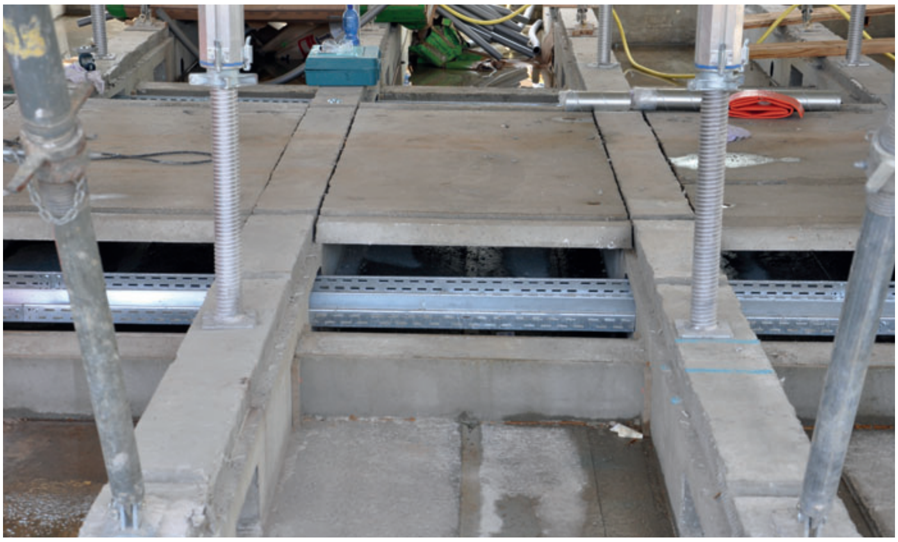
Particularly in precast component construction work, there is a long tradition with large format heavy construction components of taking the cross section apart and producing the cross section parts individually and then joining them up together mostly at a final stage. The various deformations of the individual cross section parts due to creep and shrinkage have repeatedly been the subject of different investigations.

This technique is preferred for new types of floor structures with a sandwich cross section in order to create a floor cavity. Precast panels with the lower shell and ribs in position are supplied as semi-finished components; they are completed with an upper panel at the construction site and then joined together. This can be implemented in different ways. If the slab is made from in-situ concrete, it will need non-recoverable formwork between the ribs. The formwork is set in position as a self-supporting ribbed plate made from sheet metal and acts as a monolithic unit in its final state. The bonding between the differing construction components is continuous since the connecting reinforcement from the ribs has been embedded in liquid concrete.

Prefabricated floor elements with a sandwich cross section – lower floor section with rib



Producing the upper shell from in-situ concrete; non-recoverable formwork with a profiled sheet metal plate and in-situ concrete for bonding



Producing the upper shell with precast components; panel between the ribs and bonding via discrete points along the rib line

Producing the upper shell with precast components; self-supporting precast panel positioned on the ribs and with bonding using discrete points inside the ribs

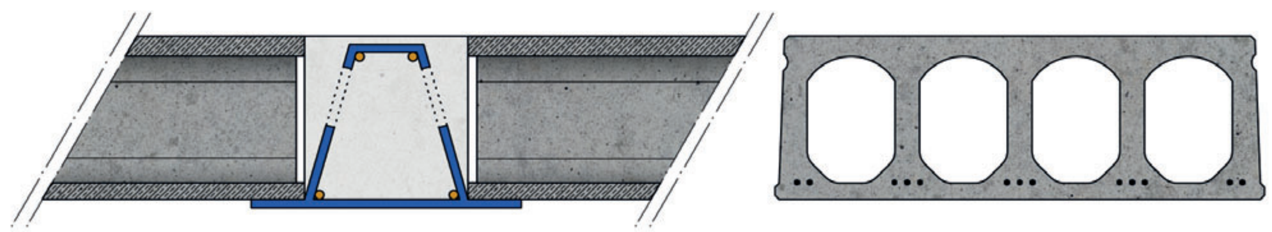
As an alternative, the upper panel can be made in each area as a precast component, which will be positioned on the ribs' side to be connected up with them by means of punctiform bonding. Concrete is then poured into the recesses created in the rib and intermediate panel.

One further alternative involves fabricating the entire upper panel as a precast component. In this process, individual openings remain in the upper panel, by means of which the punctiform bonding of both precast concrete components can be achieved.

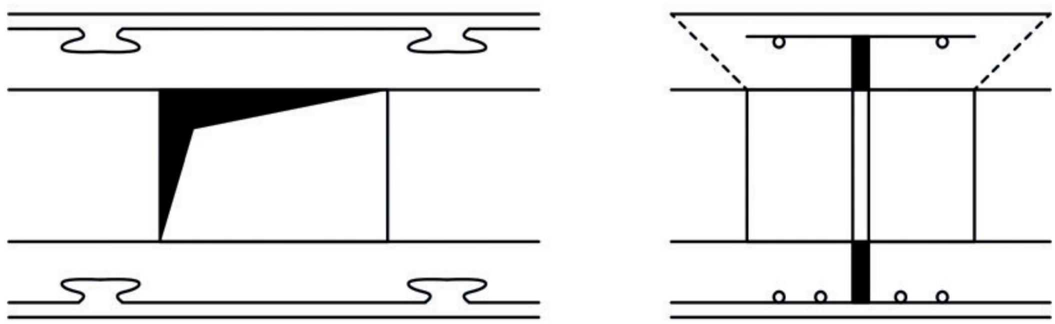
Hybrid construction components made from concrete and steel

This combination of both materials concerns a construction method that has become well known as a classic composite structure. Steel construction components with a typical steel profile cross section are joined with a concrete cross section. A rectangular concrete cross section is placed on a hot-rolled steel profile with a double T cross section. They are connected using punctiform elements such as shear studs. In this case as well, both materials are deployed according to their own particular properties. The bonding take places continually with the shear stud arrangement. Girder cross sections, adapted to requirements and set in place as a rigid element e.g. for a floor-flush flange strip, present an interesting alternative. The girder (as a rule) creates a support for prefabricated floor panels in the form of prestressed hollowcore concrete slabs. The load is transferred from the uniaxially stressed precast slabs via the floor-flush beams to the supports. A flat floor can be produced successfully in this way with prefabricated components that only transfer the load in one direction. This technology with composite girders is known by the name of "SLIM FLOORS". The bonding of the steel girder with the concrete takes place via specially shaped openings in the metal web plates.

In a similar way to this application, a single steel web plate can be embedded directly into a steel reinforced concrete rib in order to increase the load-bearing capacity of this rib. As opposed to the steel profile composed of web plate and flanges, just the single metal web plate serves to enhance load-bearing capacity in respect of transverse forces. This issue often crops up with rib plates of a low height, whose slim ribs often have large recesses. In particular, multifunctional floor panels with a sandwich cross section possess a usable cavity between the two load-bearing shells for setting in pipeline installations for building services. Pipeline cross sections (e.g. ventilation ducts) often take up the entire height available in the cavity. Since these pipelines have to cross the ribs, the recesses in the ribs have to exhibit the same height as the neighbouring cavity. Openings, whose size necessitates more or less the entire floor thickness, often have to be created in web plates in conjunction with other pipeline dimensions. As a rule in this area, no other steel reinforced

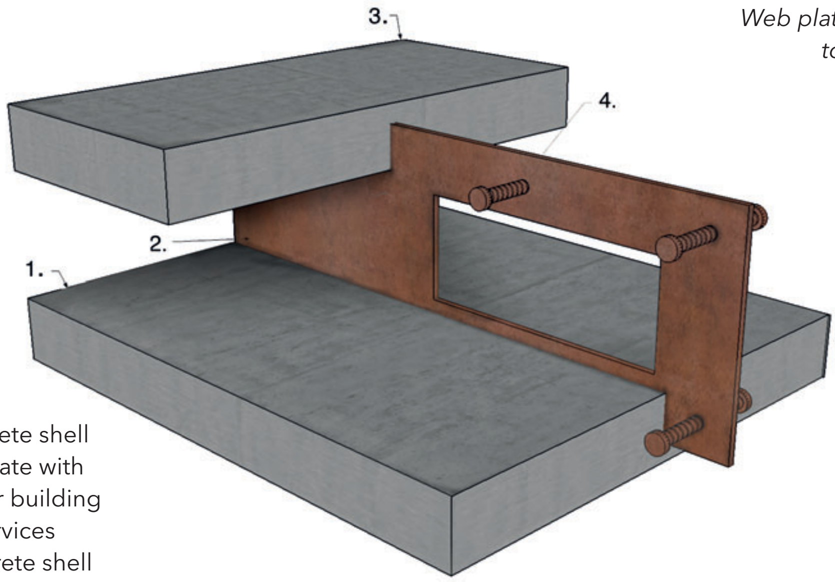


Composite girders made from profiled steel as flange strips for supporting uniaxially stressed precast components – the slim floor system



Large format openings in the web plate of floors with a sandwich cross section; the metal is capable of absorbing the transverse forces in the opening area

Web plate with large openings connected to the flange via shear studs inside the concrete



1. Lower concrete shell
2. Steel web plate with openings for building technical services
3. Upper concrete shell
4. Shear studs

structure can be envisaged, due to geometrical constraints, for absorbing transverse forces with the usual compressive and tensile diagonals. In such cases, it is necessary to absorb transverse forces and any secondary moments occurring at the recess by employing an inserted steel component in the form of a metal sheet of appropriate thickness. The recess required will then be cut out of the metal sheet itself. The sheet metal parts remaining above and below the opening then generate the resistance for absorbing the transverse forces.

The bonding between the metal sheet and the concrete is crucial in this application case as well. The upper and lower side of the web plate has to be anchored in each of the thin sandwich cross section shells. This is carried out by means of

Web plate with shear studs as components inserted into the ribs in combination with prestressing

concrete dowels, which conduct their load from the metal into the concrete. First trials with this new type of application [4] exploited the possibility offered by the continuous bonding of shear studs set into the side of the web plate. These shear studs set into the side of the web plate at its upper and lower edge project into the concrete shells. The web plates have to be prepared over their complete length to achieve this and be installed in the concrete ribs. They are made up of the metal web plate itself including the shear studs on its side, the stirrup reinforcement and prestressing cable.

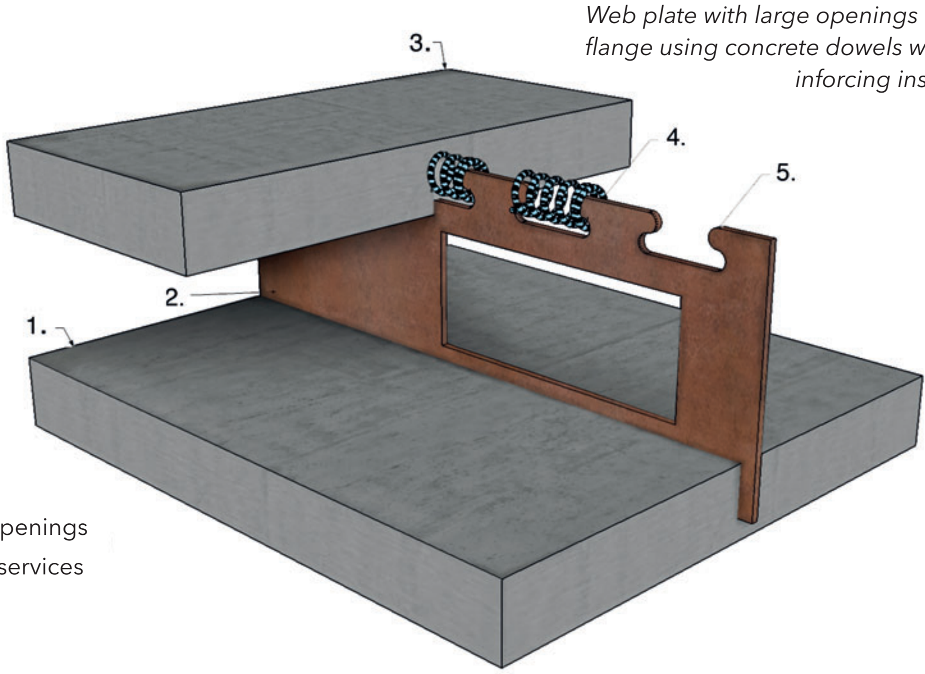
This solution is fully sufficient as regards the required capacity for shear force resistance. Economic considerations, however, demanded an alternative for replacing the shear studs. Fixing them to the web plate required great manual effort along with high energy consumption for the welded connection between shear stud and metal.

A connection with the aid of concrete dowels was found that took all constraints into consideration. This connection technique offers particular advantages when utilising metal web plates as the concrete dowel's geometrical shape can be cut straight out of the sheet metal. This means that manual effort is substantially reduced and also that energy consumption can be decreased considerably. In addition, this inserted component is far less bulky in its geometry making it easier to install in a production facility than the version with the shear studs on the side.

An economical solution for a steel reinforced composite structure was thus found with this version that has proven its worth in particular with cross sections of small dimensions. Differing floor element implementations have borne witness to the viability of this hybrid structure. The technique using concrete dowels has now become established in other applications. This joining method has been successfully tested with façade construction components with a frontal shell [5].

Hybrid construction components made from concrete and wood

Wood is generally viewed as a very sustainable construction material. On top of this, manufacturing processes for producing wooden beams are nowadays able to direct the load-bearing fibres of timber in a specific targeted direction so that great compressive and tensile stress is possible. The material is ideal for load-bearing façades especially because the timber structure can be prefabricated as a large format panels (wooden frame construction). As a construction method, it can contribute to accelerating overall construction progress.



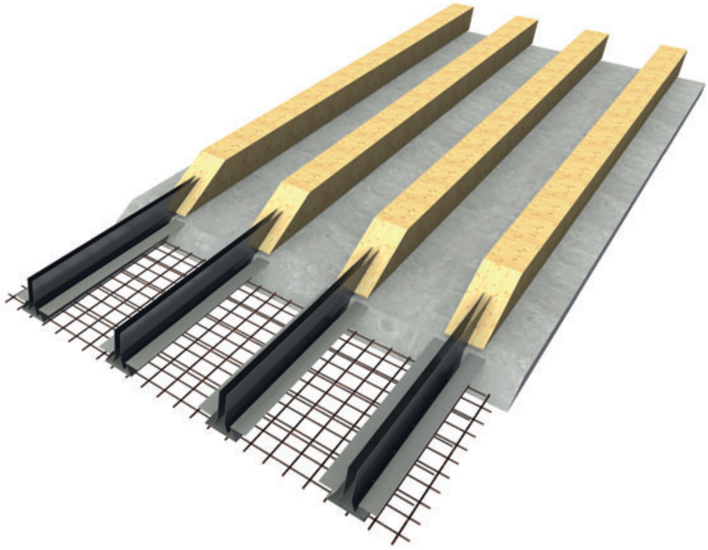
Web plate with large openings connected on its flange using concrete dowels with additional reinforcing inside the concrete

1. Lower concrete shell
2. Steel web plate with openings for building technical services
3. Upper concrete shell
4. Spiral
5. Concrete dowel

Profiled web plate to be installed in load-bearing ribs; the geometry for the concrete dowel and large format opening is cut out of the metal

Installing a web plate with built-in concrete dowels in conjunction with prestressing

Web plate installed with its concrete dowels and the areas with large openings in the web plate



System for connecting a wooden rib and concrete panel when both construction components are manufactured separately

Although, on the one hand, its low deadweight and good load-bearing capacity can be of advantage, its low mass proves to be a disadvantage in floor structures. It is generally not possible to attain sufficient noise resistance with a low mass. The possibility of installing energy efficient building component activation inside the wooden elements is also lacking. For the reasons stated, a combination of wood in the form of beams with a continuous thin concrete panel can compensate for the disadvantages of a wooden floor structure. The wooden beam is utilised in conjunction with the concrete panel to absorb external influences. At the same time, there are possibilities of combining prefabricated floor elements in an optimum manner with the wooden frame construction method for façades. The pipelines for building component activation plus all empty conduits for electrical installations are traditionally embedded in the thin concrete panel. This also creates the prerequisites for air-conditioning rooms since there is no more efficient way of heating or cooling the room's volume. The prevalence of component activation in new buildings is evidence of this fact.

However, it is crucial to pay special attention to the connection of the wood with the concrete and how it is made. The wood, a dry construction material, should not come into contact with the moist concrete during production. Some suggestions for joining both construction components already exist on the market, e.g. bolts screwed into the wood, perforated metal sheets glued into the wood plus other proposals. With these solutions, the wooden beam is fixed with the connection for the shear inside the concrete panel's formwork before the concreting procedure. This means that the wooden beam necessarily has to come into contact with the fresh concrete. It even goes so far that the wooden beam can even be soiled with concrete when the panel is concreted in a precast component production facility.

In order to avoid this procedure, a new type of connection has been developed consisting of a single inserted component made from metal for both the concrete and the wooden beam. The two construction components, each with its inserted metal component, are manufactured independently of one another. This also enables the construction component with its relevant connecting piece to be produced appropriately during the manufacturing process. These material-related components are then only joined together at a construction site. The two connecting elements are interlocked with one another and joined firmly to each other with high-performance grout. This course of action ensures that two construction components that have been manufactured individually can be handled flexibly.

Connecting wooden beams and concrete panels to a hybrid beam (Test Specimen TU Kaiserlautern)

Flexible prefabricated floor elements with web plate openings and bonding joint for the connection to the upper panel; multi-functional floor element with built-in technical building services

More flexibility with hybrid construction components

The combination of differing materials has to be taken into account when producing prefabricated elements in order to meet the specifications for high-performance, multi-functional construction components. The performance of each construction material is adequate in itself. Yet, there is still sufficient potential for enhancing both the load-bearing capacity and serviceability of structures by skilfully combining two or more construction materials to create a new type of structure. "Clever" construction components require prefabrication and the maximum exploitation of the construction materials employed. As can be seen, numerous possibilities exist of joining individual materials to make a hybrid structure.

References

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FURTHER INFORMATION

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