Development of composite columns. Emperger’s effort

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Today’s composite columns are made of structural steel, concrete and reinforcing steel. Three basic types of composite columns can be distinguished, completely encased composite columns, Figure 1a, partially encased composite columns, Figure 1b, and filled composite columns, Figures 1d and 1e. Although composite columns were rarely used from the end of World War II until the early 1970’s (Viest et al. 1997, 1.13), research had started a long time before, at the beginning of the 20th century. Combining of these materials had a number of motivations, steel columns were often encased in concrete to protect them from fire, while concrete columns were combined with structural steel as a reinforcement.

One predecessor of the completely encased column type was the so called Emperger-Column. It consisted of a cast-iron section embedded in spiral-reinforced concrete and had been used frequently in the construction of high-rise buildings in the United States. The article describes Emperger’s activities in the field of composite columns and proves his influence on the construction, which can still be felt today. Another type of today’s composite columns, the column with a solid steel core, reminds us of the Emperger-Column and can be considered as successor. It will be proved that Emperger was not only a pioneer in concrete construction, but also a pioneer in composite construction, who tried to link both steel and concrete construction techniques.

Figure 1
Types of Composite Columns (DINV ENV 1994–1–1, Fig. 4.9)
Fritz von Emperger (1862–1942)

This paragraph is based on a curriculum by Kleinlogel, dedicated to Emperger’s 70th birthday (Kleinlogel 1932). Emperger was born on January 11th, 1862 in Beroun (at that time Austria, today Czech Republic). When he began his studies in Prague in 1879, the first effects of Monier’s patents had become visible in France and evoked Emperger’s interest in the new technology. His first professional activities were in the field of railway and bridge construction. In 1890 he settled down in Chicago as a consultant engineer, where he worked on the planning of New York’s and Boston’s subways, built the first American concrete bridge in Cincinatti, Ohio and designed high-rise buildings.

After his return to Vienna in 1897, he took his Doctor of Engineering degree in 1903. Previously, he had founded the journal «Beton und Eisen» in 1901, today known as „Beton- und Stahlbetonbau“, since 1906 published by Wilhelm Ernst & Sohn, Berlin. In 1906 he gave the idea to Germany’s „Beton-Kalender“, of which he became the editor, and in 1909 he published the »Handbuch für Eisenbeton« with the same company. In 1913 Emperger was honoured by his Majesty, the Emperor of Austria, with the Knight’s Cross of the Iron Crown and in the same year received the honorary membership of the British Concrete Institute (Beton u. Eisen 1913, 187, 290). In 1932, after years of intensive research on almost every aspect of reinforced concrete and design and construction of many buildings, he became Doctor honoris causa of Dresden’s Faculty of Civil Engineering, Figure 2, and also honorary member of Austria’s Committee on Reinforced Concrete (Beton u. Eisen 1932, 50). Emperger died on February 7th, 1942 in Vienna.

RESEARCH AND DESIGN OF COMPOSITE COLUMNS

First steps

In the winter of 1901/1902 Emperger started research on concrete columns mostly reinforced with structural steel. For several reasons he had to wait until 1908 to have the specimens tested in Stuttgart with Bach. Although Emperger didn’t give explicit evidence for the problems, it can be supposed that there had been internal rivalry with his colleagues in Vienna (Emperger 1908b, Foreword). In 1907, Emperger tested three steel columns to determine their buckling loads (Emperger 1907a). After testing, one of those specimens, Figure 3, was bent back to its original shape by Emperger himself and filled with concrete (Emperger 1907b, 172). Emperger wanted to give evidence for the importance of concrete filling for steel columns. He estimated that the design formula

\[
P = \sigma_y (F_h + 15 F_c)
\]

of Prussia’s Building Regulations was unsuitable to calculate the ultimate load of a concrete-filled steel column. The number 15 defined the relation between
the modulus of elasticity of steel and concrete. Emperger found out that the ultimate load of a concrete-filled steel column didn’t depend on that number.

**Emperger’s addition-law**

In 1908 Emperger published the results of numerous tests on reinforced concrete columns, among those the specimen tested by Bach (Emperger 1908). Reinforcement was realized by both reinforcement bars and structural steel elements. According to (Gehler 1933, 266), Emperger was the first to verbalise the later well known Addition-Law: „Nach meiner Meinung ist die Bruchlast einer Eisenbetonsäule die Summe zweier Festigkeiten, die von dem Verhältnis der beiden Elastizitätskoeffizienten nicht abhängt“ (Emperger 1908, 2). In Emperger’s opinion the ultimate load of a reinforced concrete column was dictated by the sum of the strength of both steel and concrete and did not depend on the modulus of elasticity. A design formula of the Addition-Law for reinforced concrete columns was given first by (Mörsch [1902] 1912, 93), with symbols as described in the next paragraph:

\[ P = F_b \sigma_b + F_c \sigma_c \]

**Emperger’s Patent 1911**

In 1911 Emperger applied for a Patent claiming „Hohle Gußeisensäule mit einem Mantel aus umschnürtem Beton [Column of hollow cast-iron section encased in hooped concrete]“ (Pat. 291068). The spacing of the hooping had to be equal to or less than the thickness of the surrounding concrete shell, Figure 4. Because of an objection from the company Wayß & Freytag A.-G., it took five years until the patent was granted in 1916 (Beton u. Eisen 1916, 47).

In 1913 Emperger published a design formula for the ultimate load of such a column:

\[ P = F_b \sigma_b + F_c \sigma_c + F_t \sigma_t \]

where \( \sigma_t \) is the compressive strength of the cast-iron in consideration of buckling of the complete section, \( \sigma_c \) is the yield point of the mild steel and \( \sigma_b \) is the compressive strength of the concrete (Emperger 1913, 34). In the same book Emperger reported various test results of encased cast-iron columns. The column sections were varied in many ways, and solid cores were tested too, Figure 5. During the following years, numerous buildings in Austria, Czechoslovakia and the United States had been built with Emperger-Columns, but not in Germany (Kleinlogel 1928, 53). For Kleinlogel the reason had been that Germany’s building authorities rejected the application of Emperger-Columns because of missing regulations, and official tests had been refused because of Emperger’s patent claim. So in 1928 Emperger decided to give up his claims (Kleinlogel 1928, 53).

**Emperger-columns in the United States**

In 1915, Emperger gave a report on hooped concrete columns with solid cores at an engineering congress...
Emperger-Column (Pat. 291068, Fig. 2)

Fig. 2.

Emperger-Columns with Solid Cast-Iron Cores (Emperger 1913, 53, 56)

Figure 5

in San Francisco, USA. He presented his Addition-Law and pointed out that the strength of the core material was not of great importance, both cast-iron and mild steel were possible. In 1920, Emperger-Columns were regulated in the US Standard Specifications No. 23, Standard Building Regulations for the Use of Reinforced Concrete (ACI 1920). Paragraph 50 stated:

Composite columns having a cast-iron core or center surrounded by concrete which is enclosed in a spiral of not less than one-half of 1 per cent of the core area, and with a pitch of not more than three inches, may be figured for a stress of 12,000 – 60 L/R, but not over 10,000 lb. per sq. in. [69 N/mm$^2$] on the cast-iron section and not more than 25 per cent of the compressive strength . . . on the concrete within the spiral or core. The diameter of the cast-iron core shall not exceed one-half of the diameter of the spiral (ACI 1920, 302).

Emperger's Addition-Law was applied in a modified form, using a specified Tetmajer-Formula. This was the first official building regulation for Emperger-Columns. The maximum allowed compressive strength of the concrete was 3000 lb. per sq. in. (20.7 N/mm$^2$), so a column could be calculated with a maximum stress on the concrete of 4.1 N/mm$^2$. In 1928 the paragraph was amended and cores of mild steel were permitted too (ACI 1928, 824). This building regulations made it possible to use Emperger-Columns in the design of many high-rise buildings in the United States, above all in Chicago:

Buildings having the Emperger type of column, . . . include the following: Surf-Hotel, Chicago, eleven storeys; two sixteen-storey apartment buildings at
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3730–40 Sheridan Road, Chicago; Aragon Hotel, Chicago, twelve storeys; Krollick Department Store, Detroit, 150'200 ft. [46'61 m], twelve storeys, with column loads of 2,000,000 lb. [9 MN], and a building of the same size for the Detroit Pressed Steel Company. Of these, the Surf Hotel and the Krollick Store have hollow cast-iron cores (ENR 1930, 278).

Two other buildings in Chicago had been mentioned before, the 16-storey McGraw-Hill Building, see Building Case Histories, and the 30-storey Trustees Building, also known as Corn Products Building. In 1930 test results on composite columns were published by (Mensch 1930). Tests were made for the new Building Code Committee of the City of Chicago to verify Emperger’s results under American conditions. Mensch figured out «that Dr. Emperger’s claim of the strength of the composite column being greater than the sum of its components has been verified by every test» (Mensch 1930, 270).

Composite Columns in Europe

Emperger complained several times about the lack of building regulations for composite columns in Europe. «Für die beiden ... Säulenformen bestehen in keinem europäischen Staate Vorschriften [There are no regulations for these two types of columns in any of the European countries]» (Emperger 1931a, 265; similar 1930, 1931b). Emperger meant the encased steel column and his own type. At the First Congress of the International Association for Bridge and Structural Engineering in Paris in 1932, Emperger mentioned more than 1000 tests on composite columns in Europe and about 570 in North America. He distinguished four different types of composite columns. Figure 6. Type I was called structural steel column with concrete core, Type II was a steel column encased in reinforced concrete with lateral ties, Type III was called steel column encased in strongly hooped concrete, the Emperger type, and Type IV was a steel column with slight hooping. Type I and Type II are in use today, of course with modern types of structural steel elements. Type I now is called partially encased composite column and Type II is known as completely encased composite column. Columns with spiral reinforcement are neither used in concrete nor in composite construction today.

In 1931, Rudolf Saliger, Professor at Vienna University, reported several test series on composite columns of the Bauer-Type (Saliger 1931; Bauer 1930). These Columns were examined as an alternative to steel or concrete columns in two high-rise buildings in Vienna. Saliger can be considered Emperger’s rival, as he strictly avoided calling Emperger’s name in his article. Later on, Emperger had a dispute with Saliger about the application of the Addition-Law (Bauingenieur 1931, 656). During the 1930’s, additional tests in Germany were made by (Memmler, Bierett and Grüning, 1934) on steel columns filled with concrete and by (Gehler and Amos, 1936) on concrete columns reinforced with structural steel. The latter ones led to the first German building regulations on composite columns. They were passed in 1943 (DIN 1045-1943). §27d) dealt with concrete columns reinforced with structural steel, Figure 7. This paragraph existed until 1972, when the design of reinforced concrete columns was based on the ultimate load theory, and officials decided that structural steel members encased in concrete should be designed to carry the loads alone without considering the strength of the concrete (Bonzel, Bub and Funk 1972, 49). But lack of steel during war and post-war period prevented the use of composite columns in Germany. In fact, engineers were instructed to save steel by using concrete columns with a minimum of reinforcement: «zur Einsparung von Stahl ... Säulen ... zu wählen, deren Bewehrungszahl μ in der Nähe der unteren Grenze liegt» (DIN 1045–1943, 21).
Composite columns with solid steel core—Successor of the Emperger-Column

In 1965 Boll applied for a patent claiming a column with a solid steel core, with its core bearing the load and the surrounding concrete shell providing buckling safety and fire protection (Off. 1559482). Later in 1969 he tried to execute such columns in a high-rise building in Hamburg. Lack of time prevented the approval by building authorities, meaning the building had to be constructed with regular columns (Boll and Vogel 1969, 259). The connection to Emperger’s column is obvious. A solid core is surrounded by reinforced concrete, preventing the core from buckling. Strong hooping is provided too. Lateral reinforcement was to be realized using bars of 12 mm, spacing 7.5 cm, Figure 8. This type of column was first realised in 1976 in a hospital in Vienna (Krapfenbauer 1976). There are two recent examples of buildings with steel core columns, one is a high-rise building in Cologne, the so-called «KölnTurm», where steel core columns were used in the lower floors. The other is the Millenium-Tower in Vienna, completed in 1999. Because of Emperger’s connection to Vienna, this building will be described in paragraph Building Case Histories. Today, this type of column lies within the scope of Eurocode 4.

Simplified Design Method of Eurocode 4 for Composite Columns

The simplified design method of Eurocode 4 is based on the method developed at Bochum University by (Roik et al. 1976). Similar to Emperger’s Addition-Law, the ultimate load of a composite column is:

\[ N_{pl,ud} = A f_y + A_c f_c + A_f f_d \]

where \( f_y \) is the yield strength of the structural steel, \( f_c \) is the compressive strength of the concrete and \( f_d \) is the yield strength of the reinforcing steel. Buckling safety is provided by a factor \( k \), by which the ultimate load has to be multiplied. The factor \( k \) is given by European buckling curves of Eurocode 3. It has to be calculated as a function of the non-dimensional slenderness \( \lambda \).

An even more simplified design method for composite columns for the specific needs of architects and structural engineers during pre-dimensioning was developed at Aachen University by (Eggemann 2002). It determines the factor \( k \) as a function of the slenderness ratio \( L/R \), where \( L \) is the length of the column and \( R \) is the effective radius of gyration. Furthermore, numerous means are provided to calculate the effective radius of gyration of a composite column with the radius of the steel section multiplied by a correction factor \( a \).
BUILDING CASE HISTORIES

The application of composite columns, especially of the Emperger type, is illustrated in this paragraph by two old buildings and one recent example.

McGraw-Hill Building, Chicago 1929
Architect: Thielbar & Fugard, Chicago
Engineer: James B. Black, Chicago

The McGraw-Hill Building in Chicago, Figure 9, was built in 1929. It was 30 to 38 m (100 to 125 ft.) in plan and 58 m (190 ft.) high with 16 storeys over ground, confer to typical floor plan, Figure 10. Emperger-Columns were used with a solid core of cast-iron:

Cored Concrete Columns—To conserve space the designers adopted a composite column known as the Emperger type, in which the use of a solid cast-iron core permits a relatively small cross-section. The core is supplemented by the usual vertical bars and spiral reinforcement (ENR 1929, 129).

In designing the McGraw-Hill Building, the columns were made of uniform section (24 and 26 in. square [61 and 66 cm]) from basement to roof for economy, convenience and rapidity in construction . . . The variation in carrying capacity was obtained by reducing the cast-iron cores gradually from 12 in. to 3 in. (32.4 to 7.6 cm) in diameter. For the upper floors, where cores were not needed, standard hooped concrete was used (ENR 1930, 277).

A special detail of a column joint was developed, Figure 11. The cores were milled to be truly square with the axis. Each core extended 5 in. (12.7 cm) above floor level, then a pipe sleeve was placed over the core. The pipe was filled with grout and the next core was set into the pipe, adjusted and fixed in the formwork before the concrete was poured.

One curiosity has to be mentioned: In 1998 the building was demolished and by 2000 it had been
rebuilt with the original facade attached to a new structure. The feat was demanded by preservationists and City Hall. The lower part of the building now contains a shopping mall, where one can see large Lego models of the building itself and five others, e.g. Chicago’s Sears Tower and John Hancock Center (skyscrapers 2002).

**Telephone-Factory, Budapest 1930**

Architect: N. N.
Engineer: Béla Enyedi, Budapest

The Telephone-Factory in Budapest, Hungary, is one of the few documented buildings in Europe designed with Emperger-Columns. Built in 1930, it has got a framed structure with a column spacing of about 5.60 m square. For the reason of transparency and cable assembly, the structure was built without floor-beams, using flared heads instead, Figure 12. To achieve the smallest possible column proportions—the company wanted columns of less than 40 cm square with the option of adding another storey—the columns were designed according to the Emperger type, but with a core of mild steel instead of cast-iron: «[Es] wurden umschüttete Stützen mit steifen Flüßenskeletten, System Dr. Emperger, gewählt» (Enyedi 1931, 242). The columns were made of octagonal sections, 39 cm in view, and with a strong hooping (spiral reinforcement). The columns on the basement, made of ordinary reinforced concrete, 66 cm square, had more than double the cross-section area, Figure 13.
Millenium-Tower, Vienna 1999
Architect: Peichl, Podrecca and Weber, Innsbruck
Engineer: Tschemmernegg, Obholzer and Baumann, Innsbruck

The 50-storey Millenium Tower in Vienna is the tallest building in Austria, with a height of 202 m, Figure 14. After construction had been started in 1998, it took less than one year until its completion in 1999. The structure consists of a reinforced concrete core, while composite construction was used for the ceilings and columns in the office areas (Tschemmernegg 1999, 607). The exterior columns are made of concrete filled hollow sections with solid steel cores, Figure 15. The columns themselves have a diameter of 406.4 mm from first to 14th floor and 323.9 mm above. The cores were gradually reduced from 220 mm to 85 mm, and above the 39th floor no cores were needed. Eurocode 4 was used for the design of both structure and fire-resistance. Shear connection between concrete and structural steel was realised by special nails.

ABSTRACT AND CONCLUSION

During the first half of the 20th century a lot of research was done on composite columns. The combination of materials had different motivations, steel columns were often encased in concrete to protect them from fire, while concrete columns were combined with structural steel as a reinforcement.

In 1911 the Austrian engineer Fritz von Emperger (1862–1942) applied for a patent on the later so-called Emperger-Column, granted in 1916. This column was made of a hollow cast-iron section embedded in spiral-reinforced concrete. Until the 1930s, this type of column had been used in several buildings in the United States, one of them being the 30-storey Trustees Building in Chicago. In the Krollick-Warehouse in Detroit, columns reached a load-bearing capacity of 9 MN.

In 1932 Emperger gave a report on composite columns at the First Congress of the International Association for Bridge and Structural Engineering. He mentioned more than 1500 tested specimens in Europe and North America, among those were 138 tests done by himself. Emperger classified four different types of composite columns. The load
carrying capacity of a composite column was given according to the Addition-Law drawn up by Emperger, as the sum of the strength of the steel increased by that of the concrete.

Emperger complained about the lack of design rules for composite columns in Europe. He mentioned the American building regulations, which gave explicit formulas for both the Emperger-Column and the steel column encased in concrete: «Für die beiden . . . Säulenformen bestehen in keinem europäischen Staate Vorschriften [There are no regulations for these two types of columns in any of the European countries]» (Emperger 1931, 265). The research program of (Gehler and Amos, 1936) led to the first German building regulations for composite columns, defined in the German code for reinforced concrete, DIN 1045, in 1943.

It can be said that Emperger was not only a pioneer in concrete construction, but also a pioneer in composite construction. Emperger's influence on the construction is obvious. His Addition-Law can still be found in the design method of today's Eurocode 4, and the composite column type of an encased solid steel core used e.g. in the construction of Vienna's Millenium Tower, reminds us of the so-called Emperger-Column and can be accounted to be its successor.

REFERENCE LIST


