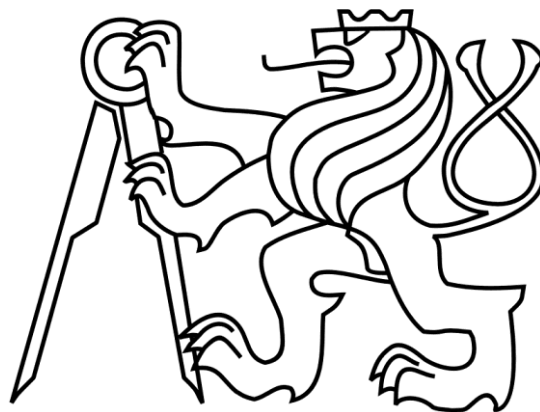


CZECH TECHNICAL UNIVERSITY IN PRAGUE

FACULTY CIVIL ENGINEERING

Department of Concrete and Masonry



**Structural Aspects of Reinforced Concrete Building
Reconstruction**

Prague 2020

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ABSTRACT: nowadays, one of the essential parts of civil engineering is the reconstruction of buildings. In this work cases of reconstruction of individual parts of structures were studied using structural analysis, considering the time dependence of used materials and their potential damage.

In this report, the case of strengthening of the build-in chimney was studied, which is made of classic red bricks (P15, 290 x 140 x 65 mm) with mortar (M5). This structure is the part of the central load-bearing mortar wall with the same building materials. The reinforcing for the studied structure was chosen to pour the Concrete P20/25 into one of the channels of the chimney. The research has shown that this method is effective, despite the problems in this method, considered and described further in detail in this work.

This paper also considers other cases with an individual approach to each problem and achieving a successful solution.

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Keywords: reconstruction, composite material, concrete, stress-strain diagram, damage, time-dependent behavior.

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1. Introduction

Reconstruction is a modern process, which does not destroy the historic construction industry, but supplements the restoration of unique buildings, adapting them to the new needs of society. The point of view about the preference for the construction of a new structure appears to be very simple. But society understands the value of heritage, for that reason the reconstruction is an important and infeasible part of the construction. From an economic point of view, restoration is a more profitable solution than building a new facility.

The reconstruction of existing buildings and structures requires additional attention to many factors that determine the construction industry. These factors are linked with an increase in loading on the structure, although a reduction in weight and loading might be provided by redirecting the load to other places or elements of the buildings.

The need to modernize or adapt to the new function of buildings makes the use of new structures and materials that must be fitted to the existing structure. The problem may arise because the structure is already old and, possibly, already has damage, and the life span of the building material may be long, thereby forcing engineers to consider the age of the object for its further modifications and to prevent an emergency stage. It is also important to consider the bond between old and new materials and their common behaviour in load-bearing function.

Regarding the popularity of reconstruction - I think this trend will continue as the growing urbanization requires more and more places for work and living in existing buildings. Therefore, it is imperative to take into account all the above parameters during reconstruction, not only for redevelopment and changing the function of the object but also for increasing its life span.

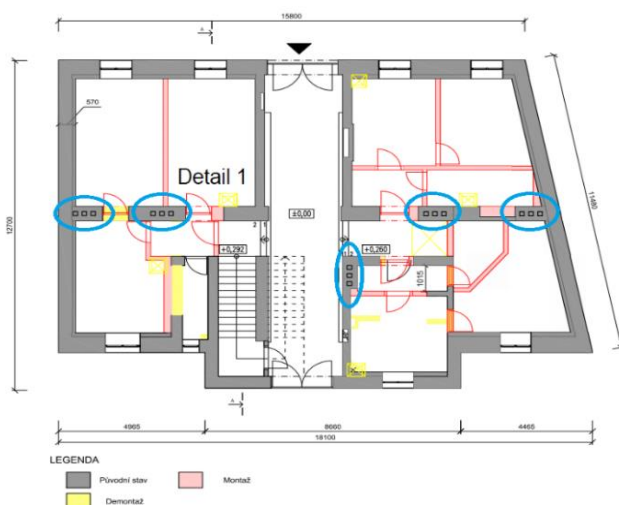
2. Modification of Masonry Chimneys

2.1. Use of Masonry Chimneys in modern world

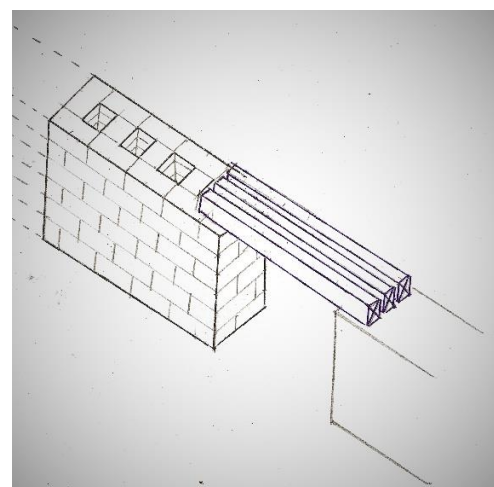
In these latter days, you can see many historical buildings that are regularly reconstructed not only externally to transform and update the appearance, but also change their supporting structures. Most of these old buildings are made of classic red brick with dimensions (140 x 65 x 240 mm). Previously, in such facilities, special ventilation holes (150 x 150 mm) were built directly in the load-bearing brick walls to divert the emissions of fireplaces outside (Fig. 1, 3). However, these Chimneys were mounted in reinforced concrete structures especially in USSR (See Fig. 2 and 3).

The main reasons why it is necessary to strengthen the supporting structure together with the Chimneys are to prepare the support for installing the door lintels (Pic. 4) and increase overall toughness. Very often you can find demolition of bearing structures for future openings since in the past such buildings did not have a large number of owners, consequently, the floor layout was designed for 2-3 families. Now it is not economically profitable, that is why buildings are being renovated, in particular, the number of doorways is increasing. For this reason, many future openings might be placed next to the Chimneys (see Pic. 4), therefore the installation of door lintels is impossible. Thus, pouring concrete into one or more ventilation openings is one of the simplest and most cost-effective solutions.

In this paper, two functions of a reinforced Chimney will be studied in detail: the first is the common strengthening of the building structure (floor + Chimney), the second is the future support for the door lintels (Fig 1. Detail 1).



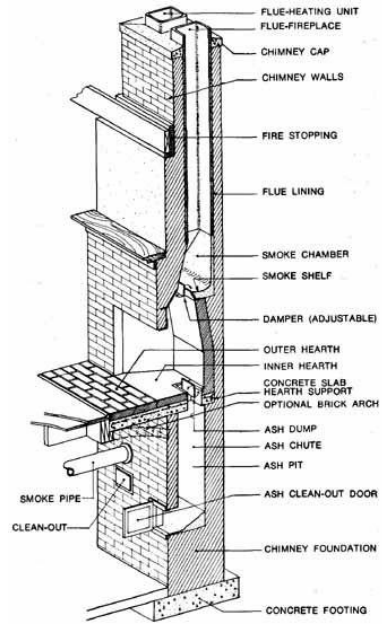
(Fig. 1: Floor Plan of historic Masonry building.)



(Fig. 1. Detail 1.)



(Fig. 2: Photo of Masonry Chimney in Concrete wall.)



(Fig. 3. 3D model of Masonry Chimney.)

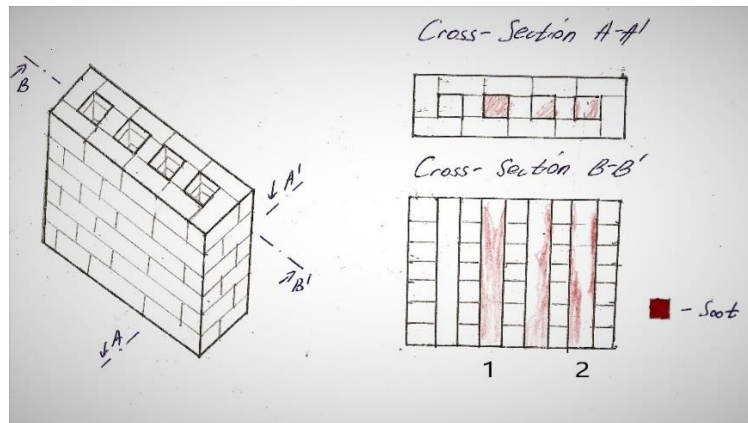


(Pic. 4: Installing the new Doorway next to the Chimney.)

2.2. Potential issues of Concreting the Chimneys

2.2.1. Remains of Soot in Chimney vents

The first and most common problem is soot deposits in the Chimney passages after many years of operation (see picture 5).

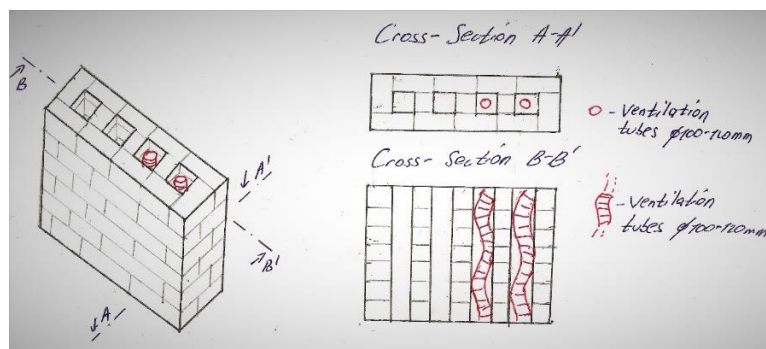


(Fig. 5. Remains of soot in Chimney vents.)

The amount of soot can be different on internal surface of Chimneys. In some cases, soot can completely block the ventilation passage (Figure 5 - 1), thereby disrupting the normal concreting of the channel with concrete. In this instance, it is necessary to clean the ventilation ducts of the Chimney before reinforcing them with concrete. If carbon deposits do not completely block the channel (Figure 5 - 2), then concreting is possible, but this will affect the quality of the bond between the concrete and the Masonry Chimney, which will entail a worse interaction of these materials.

2.2.2. Flexible ventilation tubes are installed inside the Chimneys

The further problem is Ventilation Tubes (any other types of services) inside the channels of the Chimney (Fig. 6).



(Fig. 6. Ventilation Tubes inside the Chimney.)

The historic buildings during their life-time can frequently change the type of operation thereby the services, which are listed above might be placed inside Chimneys. The reason for that decision of the location is no need to demolish any load and no-load bearing structures for placement of these services.

Commonly, the production material for these tubes is steel or aluminium. They are placed from the floor, where the boiler is located and end on the top of the roof to extract a used air from a structure. Despite that fact, throughout decades of operation of the historic buildings, these technical services might be demolished or damaged. Nevertheless, in the case of strengthening Chimneys and preparing future support for lintels, it is necessary required to check, whether these ventilation vents are opened and not blocked at any point for concreting. In the worst case, the future concrete in Chimney channels would not be inside the ventilation tubes, but only in small portions outside of them.

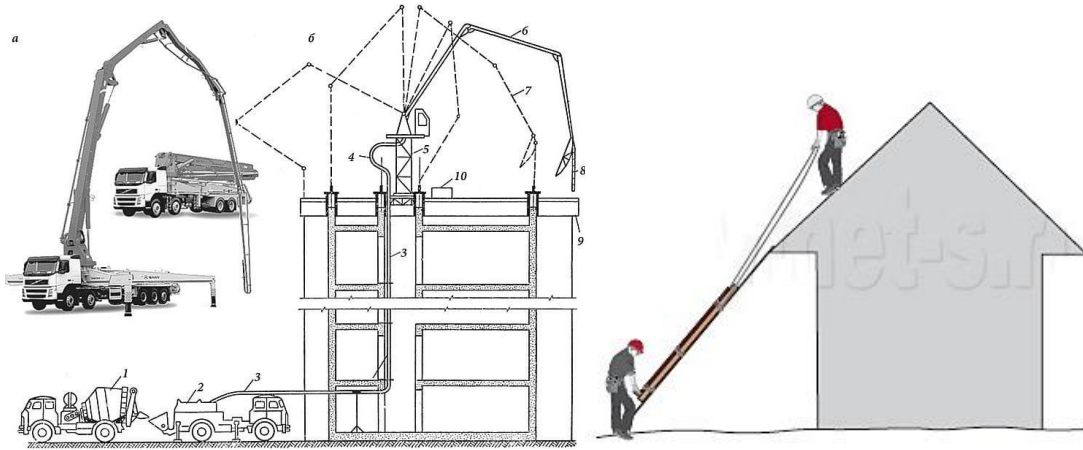
2.3. Technology of Concreting the Chimneys

Before pouring the concrete mixture into the ventilation channels, a set of operations have to be performed to prepare the surfaces of the existing structure. Ignoring the basic procedure leads to the poor quality of a final product or in the worst case to the failure.

A desire Chimney has to be measured from the parapet on the roof in order to check and control the clearance of the passages. It might happen, a particular Chimney has different length of individual channel, due to the design of initial project of a structure. If it is required, the passages have to be cleaned up for improving the mechanical properties of future combined structure.

2.3.1. Concrete delivery to the worksite

First of all, it has to be decided how the concrete will be supplied to the top of the roof. Opportunities vary, respectively to the scale of reconstruction and shape of the roof (pitched or flat). In case of a large scale of the reconstruction project, the concrete mixture can be transported from outside by Concrete Mixer with Sleeve or Crane, which pump the material under pressure on different heights (shown on the Pic. 7). If the reconstruction project is small the concrete is delivered in batches or baskets manually by workers (Pic.8).



Pic. 7: a) – Agitator Truck with Sleeve

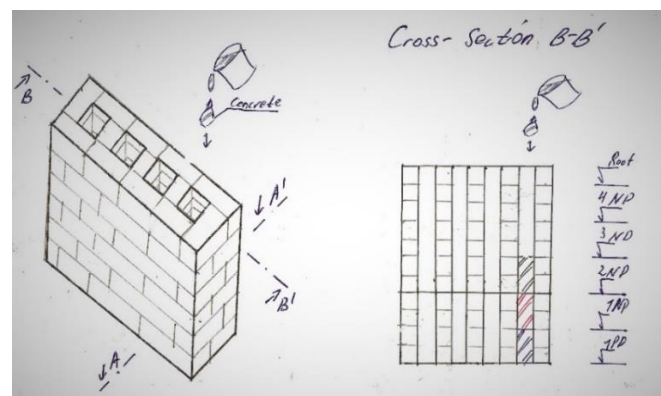
(Pic. 8. Delivering Concrete manually.)

b) – Crane with Pumping System

2.3.2. Concreting the Chimney

2.3.2.1. Concreting the Chimneys without services inside

Right before placing the concrete mix, the cleaned surfaces of a Chimney must be washed with water and dried with an airstream, to eliminate a large amount of water being absorbed from fresh concrete to the old structure. The concreting will be splitting to several stages (see Fig. 9). In each stage the mixture will be poured by the floor height one by one, to exclude the overpressure on 140 mm interlayer brick inside the Chimney, it may occur that the outer layer of the brick can be destroyed, while the doorway opening was made (see Photo 28). In the case of overpressure of this brick layer, the collapse of it can be resulted (Pic 4 concreted Chimney side after failure of demolition). To ensure solidity, it is desirable to concrete the structure continuously without interruption. Immediately after pouring the desire portion of Concrete the vibration is provided. In this particular case the Mobile Electric Vibrator with long wire will be used (Fig. 10). Surely, this procedure is used for all stages.



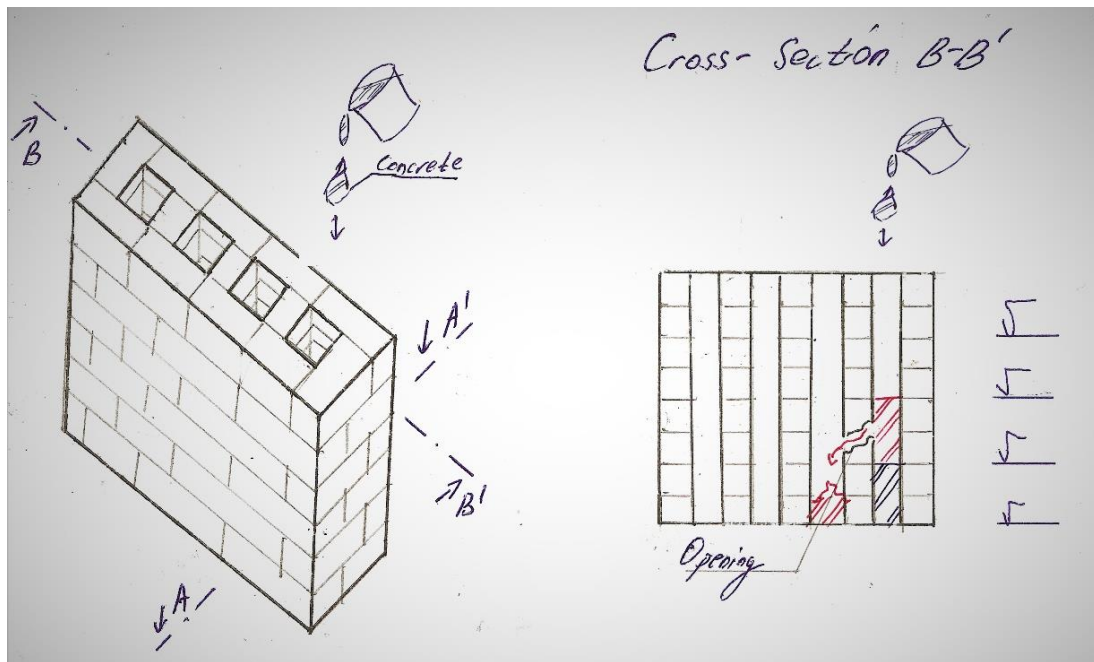
(Fig. 9. Concreting the Chimney in stages.)



(Fig. 10. Mobile Electric Concrete Vibrator.)

Laying the next layer of a concrete mixture is allowed before the beginning of the setting of the concrete of the previous layer. In case of failure, the joint between the old and new concrete layer will be formed due to the long break in concreting. This usually happens during breaks in concreting from 7 hours. For that reason, each stage will last approximately 5 hours, to get the fresh concrete get consolidate enough to reduce the pressure from Chimney walls, meanwhile avoiding the joint in concrete. The reason for splitting to stages is to control whether the Chimney channel has no kinds of openings or connection between the Chimney shafts (see Pic. 11).

To control the level of the individual stage the steel pendulum on a rope is used for quick and easy check (shown on the Fig. 12). The regular size of the pendulum is approximate 5 – 8 cm. in length and the mass of it varies about 170 – 280 g, which makes the measuring very simple without any difficulty. In case of not matching the desired height of a specific stage, it is recommended to pour an extra portion of Fresh Concrete mixture up to the required level. The measurement should be provided several times. Firstly, right after the concreting, if the difference in desire and real level appear that means, that there is a big intersection between Chimney openings. The proper solution for that would be to continue pouring the mixture up to the proper height of the fresh concrete column. The next measurement should be done in 2-3 hours, if any variation arises, adding very carefully and slowly an extra mixture is followed. A further check is better to provide approximately 5-6 hours after (first) concreting. In this particular case, in case of reasonable deviations, there is no need for adding a new portion of the mixture.



(Pic. 11. Openings in Chimney Shafts.)



(Fig. 12. Pendulum on rope.)

2.3.2.2. Concreting the Chimneys with Ventilation Tubes inside

Occasionally ventilation services might be found directly in the Chimney channels (see Photo 13.1 and 13.2). Usually, these tubes are made of Stain-less Steel or Aluminium alloy in order to resist high temperatures from the boiler, which heats up the water for a building and for heating system.

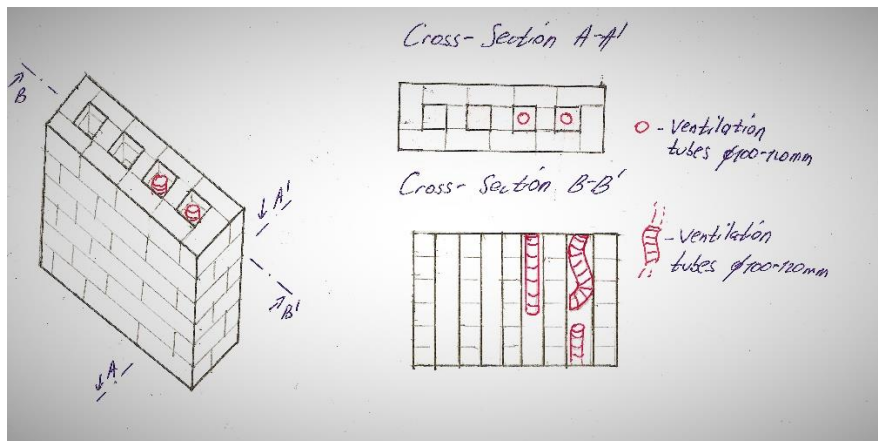


(Photo. 13.1 (on the left) and 13.2 (on the right). Stainless Steel Flexible Chimney Tube.)

The steel duct is opened from top (see Fig. 6), pouring the Concrete mixture in it is not complicated, despite of that a constructor has to set up the goals for concreting the channels. The reason for that is that there are 2 options: fully concreting the duct for creating the desire support for Lintels; Concrete the Chimney vent out of tube, but save its functionality (in Figure 6 the left tube is relevant for this case).

In the case of blocked tubes (Figure 14), the proper solution will be to make observation holes by drill (see photo 16) approximately every 1 meter and see where the duct ends or interrupts. When the desire point of interruption is established, the cutting with Circular Saw (photo 25) is continued, in order to get the access to that location and free the vent tube from the capture, for future concreting.

If the steel or Aluminium duct is interacting with several Chimney channels (as shown on the photo 13.1), there is no need to cut the duct in the point of intersection, but it is recommended to reinforce it in that point by steel rods, to eliminate any movement of tube while concreting, the technique of reinforcement will be described in details further in the work.

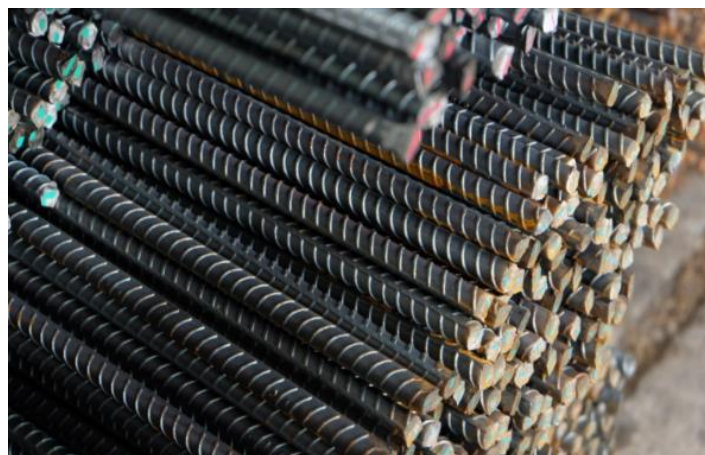


(Figure. 14. Pendulum on rope.)

However, all of these alternatives have the same technology for reinforcing before concreting the air shafts. Moreover, straight ventilation system has no issues with noises, once the duct is buckled, the noises appears and disturbs people, who live in the building. Also, the condensation can be accumulated in the case of bended tubes, which leads to fungus. This mould leads to destruction of tube and Concrete in future.

2.3.2.3. Reinforcement of ventilation tubes with steel rods

Reinforcing of Chimney channel should be provided with casual steel rebars (see Pic. 15). The main idea of reinforcement of Stainless Steel or Aluminium ducts is to fix them at specific points, in order to eliminate any failure or buckling of these tubes while concreting.



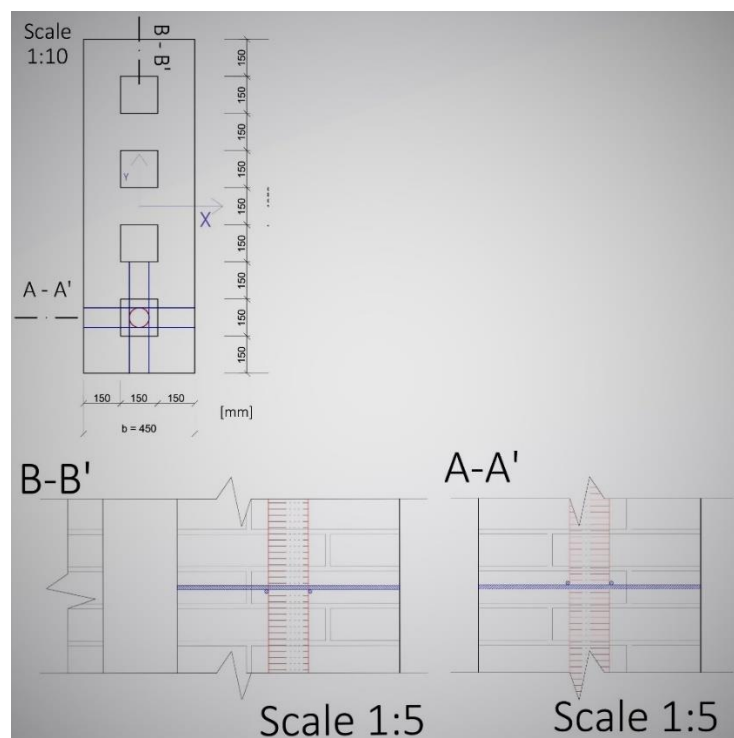
(Pic. 15. Conventional steel rebars.)

In the first place, the drilling of holes with the Drill (Picture 16) is performed in directions, which are showed in the following scheme (scheme 17). Some deviations or penetration the duct with steel rebar is allowed, but not recommended. Definitely, the drilled

holes should be slightly bigger, than steel rebars by several millimetres (as an example, drilling with $\text{Ø}12\text{mm}$ and insertion with $\text{Ø}10\text{mm}$. Hence, 4mm reserve is left). Otherwise, it would be impossible to insert these steel bars. For example, a worker might drill not perfectly orthogonally, thereby embedding the rods will be tough and time consuming.



(Pic. 16. Drilling holes with long rod.)



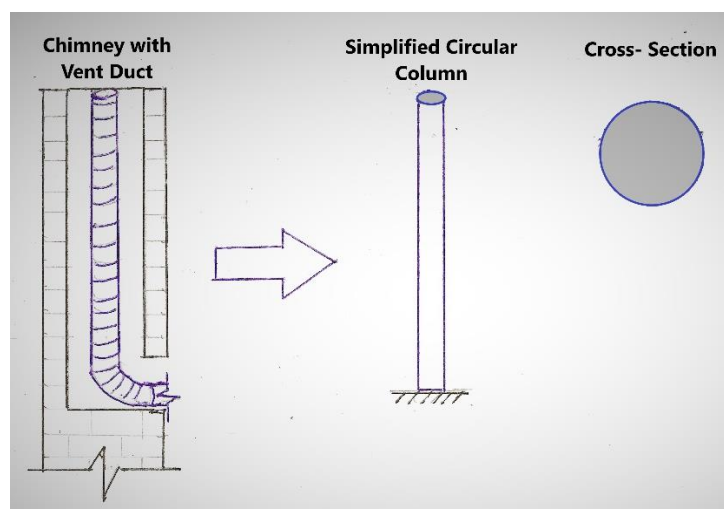
(Scheme. 17. Drilling holes with long rod.)

Then steel bars are inserted to these holes and cemented from outside with adhesive (as shown on the Figure 18). In this specific case, the adhesive has to be injected from both sides of future single rebar. As soon as injection is made, the steel bar is inserted. It might happen, that the mixture might be pushed out from the hole, thus the adhesive is pushed to the after the installation of rebars and left for consolidation.



(Figure. 18. Injecting the adhesive.)

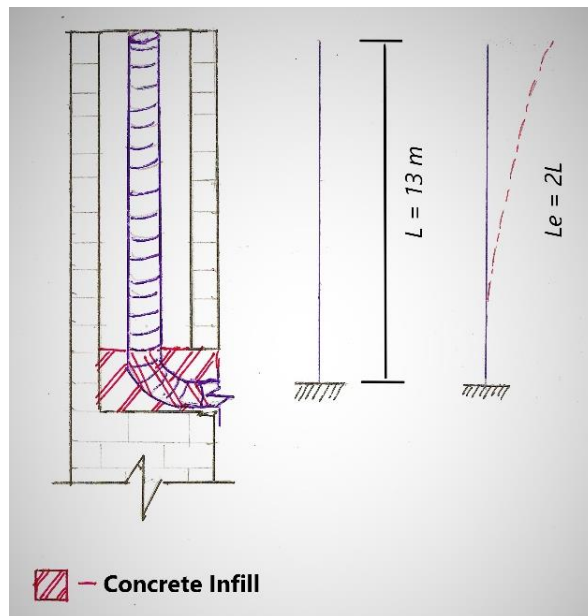
Our steel or aluminium ventilation duct we can estimate as the column with the same material properties, but with non-hollow circular cross-section of the same area (as presented on the scheme 19). It will help us to apply formulas of Euler to calculate the critical load on the column and check the critical stress on the cross-section.



(Scheme. 19. Simplified Supported Column.)

Let us consider the ideal case, where the Aluminium ventilation Duct with External Diameter (E.D.) of 80 mm and the wall thickness of 2 mm is straight column with fixed support on the bottom and free end on top. The reason for fixed support is that from concreting of the

bottom of the duct will be provided at first before any stage of pouring the Concrete in the Chimney, in order to fix the vent tube (see Sketch 20).



(Sketch. 20. Static scheme of Fixed-Free Column.)

Calculation of Critical Force in ideally straight Aluminium duct

- Moment of Inertia

$$I = \frac{\pi * (Re^4 - Ri^4)}{4} = \frac{\pi * (0,04^4 m^4 - 0,038^4 m^4)}{4} = 3,7295 * 10^{-7} [m^4]$$

- Young`s Modulus

$$E = 68 [GPa] - \text{Alluminium Alloy}$$

- Area of the cross-section

$$A = \frac{\pi}{4} * (De^2 - Di^2) = \frac{\pi}{4} * (0,08^2 m^2 - 0,076^2 m^2) = 0,0004909 [m^2]$$

- Radius of Gyration

$$i = \sqrt{\frac{I}{A}} = \sqrt{\frac{3,7295 * 10^{-7} m^4}{0,0004909 m^2}} = 0,027586 [m]$$

- Slenderness ratio

$$\lambda = \frac{L_{eff}}{i} = \frac{26m}{0,027586m} = 942,499 [-]$$

From that Slenderness ratio follows, that we can apply Euler formula to calculate the Critical Force for this Column and Critical Compressive Stress of cross-section.

- Critical Force

$$P_{cr} = \frac{\pi^2 EI}{(L_{eff})^2} = \frac{\pi^2 * 68 * 10^6 \text{KPa} * 3,72957 * 10^{-7} \text{m}^4}{(2 * 13 \text{m})^2} = 0,3703 \text{ [kN]}$$

- Critical Compressive Stress of cross-section

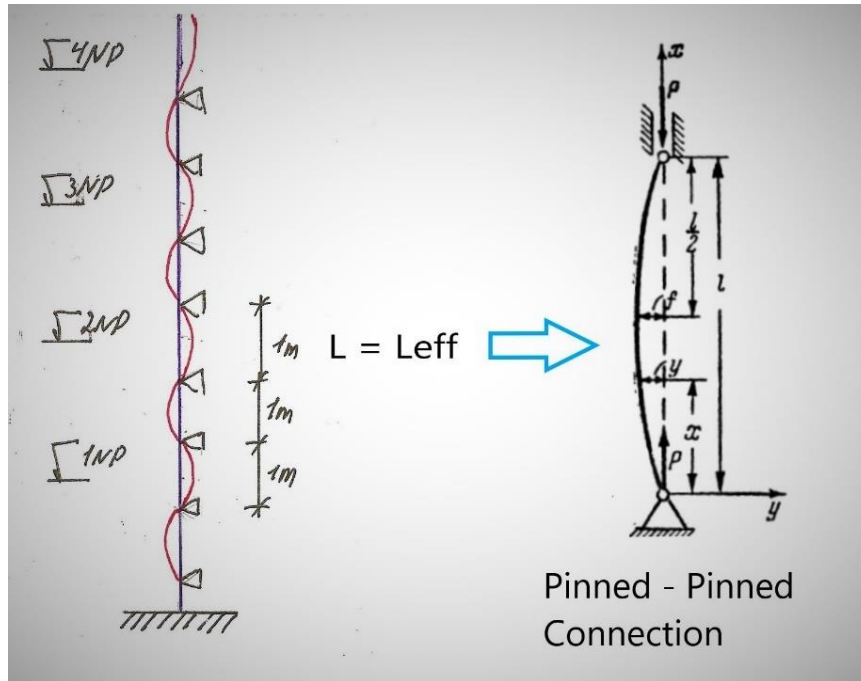
$$\sigma_{cr} = \frac{P_{cr}}{A} = \frac{0,3703 \text{kN}}{0,0004909 \text{m}^2} = 755,52114 \text{ [kPa]} = 0,756 \text{ [MPa]}$$

$$\sigma_{cr} < \sigma_y; 0,756 \text{MPa} < 30 \text{MPa} \quad \Rightarrow \text{OK}$$

There is no failure in yield strength of Aluminium under the Critical Load.

From these calculations we can state, that our Aluminium Column will not fail under the Critical Load, on the other hand, due to small area of cross-section the given Column can withstand literally small axial load. If our RMC will have ideally straight without any inclination Aluminium duct, we can pour the Concrete firstly from sides of the duct, to increase the stability of the tube, then pour the mixture inside of it.

Unfortunately, in real life we have imperfections and occasionally bended ventilation tubes inside a structure. For that reason, we will assume wavy duct with some loading from the fresh Concrete (see sketch 21 below) and estimate the distance for future supports with intervals. Let us consider the support of our tube to be with the interval of 1 m along the whole height of the structure. Subsequently, we will receive 2 steel rebars mesh or in other words supports (scheme 16) in each floor. From that assumption we obtain the next static scheme for axial loaded column.



(Scheme. 21. Euler Modes of Buckling Columns.)

Calculation of Critical Force in supported Aluminium duct

- Moment of Inertia

$$I = \frac{\pi * (Re^4 - Ri^4)}{4} = \frac{\pi * (0,04^4 m^4 - 0,038^4 m^4)}{4} = 3,7295 * 10^{-7} [m^4]$$

- Young`s Modulus

$$E = 68 [GPa] - \text{Alluminium Alloy}$$

- Area of the cross-section

$$A = \frac{\pi}{4} * (De^2 - Di^2) = \frac{\pi}{4} * (0,08^2 m^2 - 0,076^2 m^2) = 0,0004909 [m^2]$$

- Radius of Gyration

$$i = \sqrt{\frac{I}{A}} = \sqrt{\frac{3,7295 * 10^{-7} m^4}{0,0004909 m^2}} = 0,027586 [m]$$

- Slenderness ratio

$$\lambda = \frac{L_{eff}}{i} = \frac{1\text{m}}{0,027586\text{m}} = 36,258 [-]$$

We received the small Slenderness ratio, which represents the sturdiness material property. If the ratio is low ($<80 \approx 100$), that means that we have robust column and Euler Formula can not be applied directly. The Euler considered the material has to be robust enough and obey the Hooke's Law. As it is known, a material follows the Hooke's Law until the stress in it reaches the limit of proportionality. Therefore, Euler's formula for different materials should also have their limits of applicability. It is valid only as long as the critical stress in the rod does not exceed the limit of proportionality to the material. In short rods, the critical stress, determined using the Euler formula, is obtained above the ultimate strength. Therefore, for short rods, Euler's formula is not applicable.

The limit of application of the Euler formula will be the case when the critical stress is equal to the proportionality limit. On the basis of this, for any material, it is possible to determine those limiting values of the ratios of the geometric dimensions of the column, up to which the Euler formula is applicable.

Substituting the elastic limit in the formula instead of the critical stress we obtain the following:

- Slenderness ratio

$$\lambda \geq \sqrt{\frac{\pi^2 * E}{\sigma_{el}}} = \sqrt{\frac{\pi * 68 * 10^3 \text{MPa}}{30\text{MPa}}} = 84,386 [-]$$

$36,258 \ngtr 84,386$ that means, that critical stress will be higher, than elastic stress of the Aluminium column, thus Euler's formula in this case is not acceptable.

In order to find the Critical Force for the given short column (for which Euler's formula is not applicable) can be determined by the empirical equation of Yasinsky:

- Critical Compressive Stress of cross-section

$\sigma_{cr} = a - b * \lambda$, where a and b – values, depending on material. These values can be found in books (for Aluminium alloy: $a = 380$ [MPa], $b = 2,185$ [MPa], $\lambda_{cr} = 51$ [-])

$$\lambda \geq \lambda_{cr}; 84,386 \geq 51 \quad \Rightarrow \quad \text{OK}$$

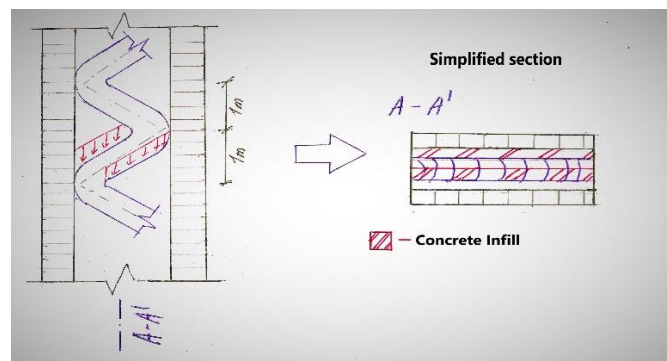
$$\sigma_{cr} = 380 - 2,185 * \lambda = 380 \text{ MPa} - 2,185 \text{ MPa} * 84,386 = 221,6173 \text{ [MPa]}$$

- Critical Force

$$\sigma_{cr} = \frac{P_{cr}}{A} \Rightarrow$$

$$P_{cr} = \sigma_{cr} * A = 221,6173 * 10^3 \text{ kPa} * 0,0004909 \text{ m}^2 = 108,612 \text{ [kPa]}$$

As we can mention, our Critical Load increased almost at 300 times in the case of supported Aluminium duct at each 1 m, than just fixed on one end and free on another end duct. For simplicity we might conclude, that this modified column with supports became robust enough to resist any loads, caused by pouring the fresh Concrete inside and outside of it.



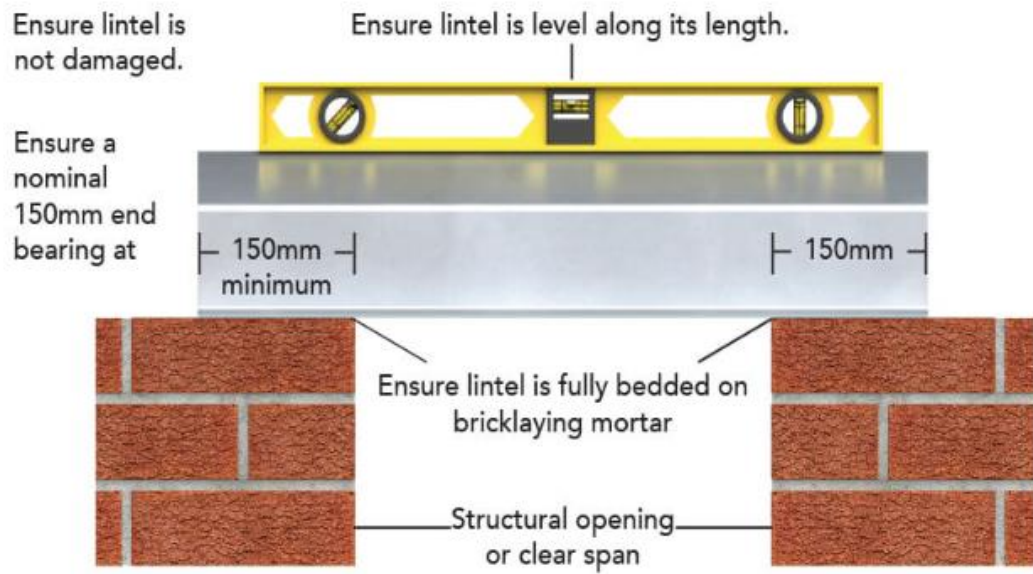
(Sketch. 22. Extreme loading from fresh Concrete to the Aluminium duct.)

2.4. Technology of installing Lintels

In this chapter, the technology of the installation of Lintels is described. This technic is essential in reconstructions and it can not be ignored, otherwise, the results might be heavy or fatal. Quite often workers unadvisedly do a job, thereby the control of the quality of their work has to be provided. Even the new Lintels are placed on their position, for some time with the integrated structure with these Lintels might hold on and bear some loading, but in time the cracks and damage to the load-bearing structure will increase.

The most important thing the constructor has to do is to check the undamaged Lintels. If they are damaged, the constructor or owner immediately has to exchange the product. The damaged Lintel(s) might suddenly break or lose their stiffness and load-bearing capacity. In this case, the failure of part of the structure is ensured. A further check is to control the desired

length of Lintels. Sometimes, the supplier of steel products sells the metal pieces, which are left on their warehouse or they are not able to cut precisely the desire length of the metal product. The minimum length of the Lintel end on one side has to be more or equal to 150 [mm] (see Fig. 23), but in our specific case, it will be 200 [mm] with an eye to increase the support stiffness (Masonry Chimney and Concrete infill). Only after these fundamental checks, the installation of them can be started.



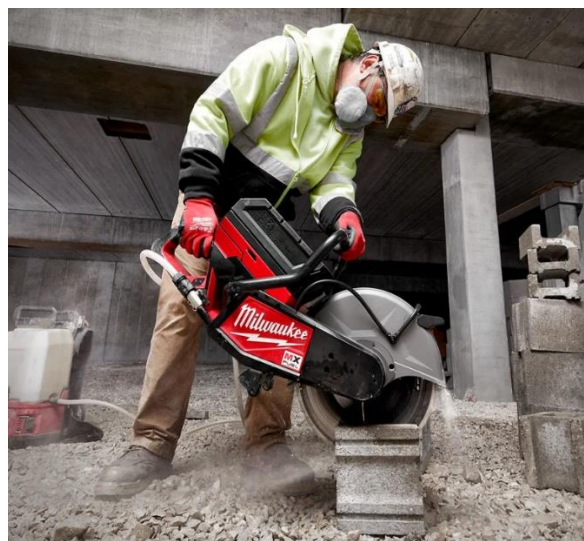
(Fig. 23. Basic rules of Installation of Steel Lintels.)

The initial step will be drill through the holes with drill directly to the location, where the desire door opening will be. It is recommended to drill one hole directly in the middle and two other holes on the edge of future opening (as shown on the Photo 24). The reason for that is to eliminate unprecise or sometimes deadly cuts or perforated positions for future location of the Lintels. Even with really good floor plans of a building some mistakes or differences in length and positions of specific objects are incorrect. These method for drilling some holes vanish any doubts of desire location of Lintels. Perforating is not suggested especially in the historic buildings, any excessive vibrations of load-bearing elements will stimulate cracks and delamination of the structure.



(Photo. 24. Drilling holes in the location of future doorway opening.)

The next step is to prepare the room before cutting the wall. The circular Saw with water supply further will be used (Photo 25). The foil should be placed all around the new position of cut (see Photo 26), because the saw will splash the water with concrete or masonry dust all over the place and it might happen, that water can hit the electric circuit and shut down the hole construction site or even cause lethal cases of workers, in the meantime working with this equipment.



(Photo. 25. Mobile Circular Saw with water supply.)



(Photo. 26. Prepared location for cutting a wall with Circular saw.)

Further, the actual cutting is starting (see Photo 27). In this stage the essential goal is to control the levelling of the saw. If the final cut will be skew, the perforation will follow, but as it was already mentioned above in this chapter, it should be avoided at any cost or only as a last resort to refer to this. Moreover, the constructor will pay an extra time and money for it. The first cut should have $\frac{2}{3}$ of the wall thickness, in order to insert middle and side Lintels at once. Definitely, the size of opening for Lintels should include some reserves about 2 cm. The reason for this is that after perforation the position for Lintels will be not perfect and smooth.



(Photo. 27. Cutting the wall with Mobile Circular Saw.)

When the cut from one side of the wall is complete (see Photo 24), the perforation of the cut element is followed. When the cut is made, the delamination of this piece will be much easier, so make sure to cut it properly and deep enough along the hole length.

The installation of Lintels follows after perforation. The constructor should check before the installation the proper Lintels for specific opening. Misunderstanding can occur (see Photo 28). The engineer is designing the special Lintels and their position in the wall. Workers may not pay attention to these details and place randomly the Lintels.

Firstly, the middle Lintel is inserted to the artificial position for it, then underpinning of the Lintel is made with the help of metal plates or metal wedge (see Photo 29). The interval between each wedge should be around 7-10 cm. In other words, they should be laid frequently. That technique prevents the local damage and settlement of the structure above the new Lintels. Because of reserve, which was mentioned above, after installation of metal profiles, the air gap appears, in order to force the profiles work, the steel wedges work as interlayer between the structure and Lintels and transform the loading respectably. In the same manner the outer Lintel is inserted and underpinned by metal wedges.



(Photo. 28. Failure of installation of Lintels.)



(Photo. 29. Underpinning of metal Lintels by wedges.)

Right after the underpinning the Lintels, the formwork has to be mounted around the Lintel and Concrete mixture is poured inside of it (see Photo 24). The freshly installed Lintels with Concrete mixture are left for hardening at least for 24 hours to get the fresh Concrete mixture harden.

On the next day the cutting of lintel gap is made with circular saw, the Concrete is extracted and the last Lintel is inserted and underpinned with following concreting (Photo 24).

The final step is perforating the doorway opening after the hardening of Concrete mixture in the Lintel. The boundary of the doorway is cut with Circular Saw (Photo 30). Only after disintegration of the wall by saw, the fragmentation with perforator may be done (Photo 31). The saw is used here for splitting the wall structure to eliminate excessive vibrations on the wall structure by perforator. Moreover, the perforator can not make the ideal line between demolished part and existing part, it increases the price for correcting these imperfections, rather than cut edges after the circular saw.



(Photo. 30. Cut the doorway opening.)

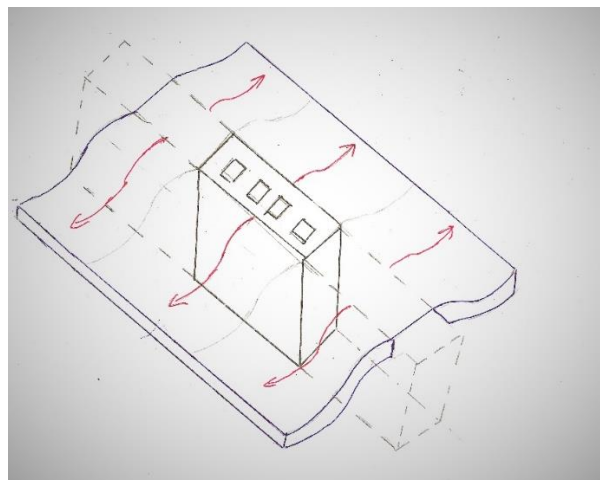


(Photo. 31. Demolition of the Doorway with perforator.)

3. Structural analysis of Reinforced Masonry Chimneys (RMC)

3.1. Increase of overall Load-Capacity (L-C)

To the perspective of increasing the overall strength of the given structure (Fig. 1), we consider the working direction in direction of the arrows (see Fig. 32). The reason for that direction is that the Reinforced Concrete (RC) Floor made of Steel I-Profiles and metallic sheet with RC on it is supported on the Masonry load-bearing wall (shown Photo 33), where the given Chimney is located. Because the RMC is mounted in the load-bearing structure, it will behave together with this wall, which will distribute part of its stresses and create an eccentricity in the Chimney structure.



(Fig. 32. Behaviour of the structure under the loading.)



(Photo. 33. Behaviour of the structure under the loading.)

3.1.1. Interaction Diagram of Masonry Chimney (increase of L-C)

Interaction Diagram - Masonry Chimney

- Compressive Strength of Masonry Unit

Brick (290 x 140 x 65 mm) – P15 [MPa]

$f_u = 15$ [MPa] - Mean Compressive Strength of the Brick

Mortar (1:0:3) – M5 [MPa]

$f_m = 5$ [MPa] – Compressive Strength of the Mortar

$f_b = \eta \times \delta \times f_u$ [Mpa] – Normolised Mean Compressive Strength

η – coeff. according to type of conditioning = 1

δ – effect of width and height of the masonry unit = 0,75

$f_b = 1 \times 0,75 \times 15\text{Mpa} = 11,25$ [MPa]

$$f_k = K f_b^\alpha f_m^\beta$$

Characteristic Compressive Strength of the Masonry

K – coeff. depends on type of masonry unit and mortar = 0,55 EN.1996.1.1.2005 - Tab3.3

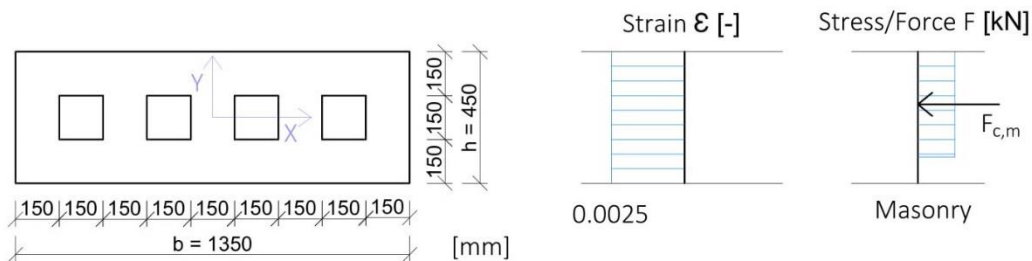
$$f_k = 0,55 \times 11,25^{0,7} \text{ MPa} \times 5^{0,3} \text{ MPa} = 4,85 \text{ [MPa]}$$

$$f_d = \frac{f_k}{\gamma_M} \text{ [MPa]} - \text{Design Compressive Strength of the Masonry Unit}$$

γ_M – partial safety factor = 2, EN.1996.1.1.2005 - 2.4.3

$$\frac{f_k}{\gamma_M} = \frac{4,85}{2} = 2,43 \text{ [MPa]}$$

1. Point 0 – Pure Compression



1.1. Normal Force

$$N = F_{c,m}$$

$$F_{c,m} = 0,8 \times (b \times h - 4 \times 0,15^2 \text{ m}^2) \times f_d \text{ [kN]}$$

- $N = 0,8 \times (1,35\text{m} \times 0,45\text{m} - 4 \times 0,15\text{m} \times 0,15\text{m}) \times 2,43 \times 10^3 \text{ kPa} =$
 $= 1006,02 \text{ [kN]}$

1.2. Moment

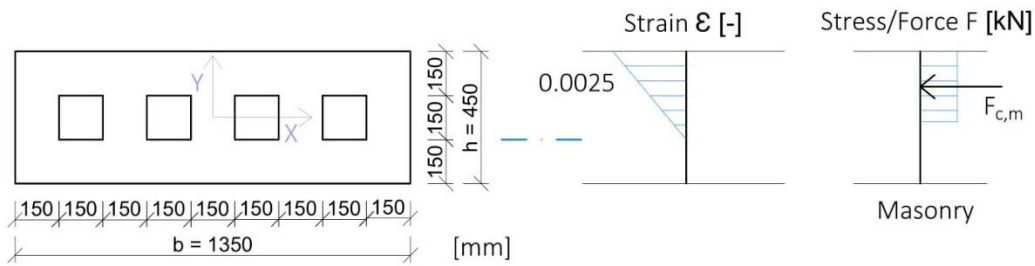
$$M = F_{c,m} \times D_{p,c}$$

- $M = 0 \text{ [kNm]}$

1.3. Plastic Centroid (P.C.)

P.C. is in the middle because the C-S is symmetric. Thus, there is no Lever Arm for the Moment in this case.

2. Point 1 – 1st border of C-S change



2.1. Normal Force

$$N = F_{c,m}$$

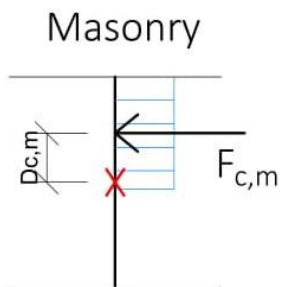
$$F_{c,m} = 0,8 \times (b \times (h - 0,15m) - 4 \times 0,15^2 \text{ m}^2) \times f_d \text{ [kN]}$$

- $$N = 0,8 \times (1,35m \times (0,45m - 0,15m) - 4 \times 0,15m \times 0,15m) \times 2,43 \times 10^3 \text{ kPa} =$$

$$= 612,36 \text{ [kN]}$$

2.2. Moment

$$M = F_{c,m} \times D_{c,m}$$



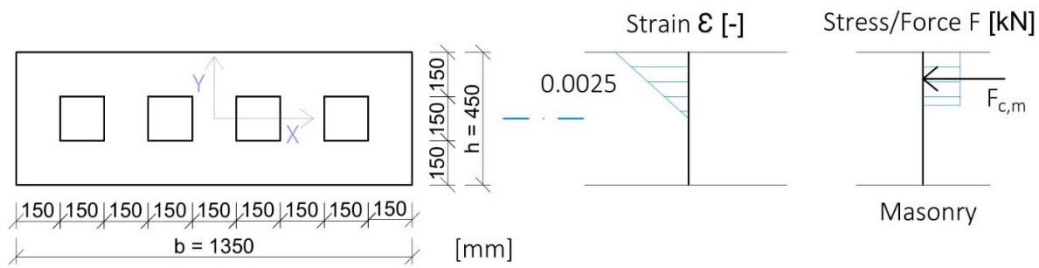
X - Plastic Centroid

$D_{c,m}$ – Lever Arm [m]

- $$M = 612,36\text{kN} \times \left(\frac{0,45m}{2} - \frac{0,8 \times 0,3m}{2} \right) =$$

$$= 64,298 \text{ [kNm]}$$

3. Point 2 – Centre of C-S



3.1. Normal Force

$$N = F_{c,m}$$

$$F_{c,m} = 0,8 \times (b \times (h / 2) - (4 \times 0,15^2 \text{ m}^2) / 2) \times f_d \text{ [kN]}$$

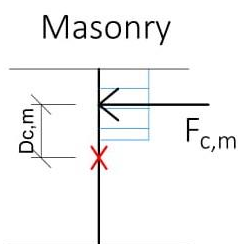
- $N = 0,8 \times (1,35\text{m} \times (0,45\text{m} - 0,225\text{m}) - (4 \times 0,15\text{m} \times 0,15\text{m}) / 2) \times$

- $* 2,43 \times 10^3 \text{ kPa} =$

$$= 503,01 \text{ [kN]}$$

3.2. Moment

$$M = F_{c,m} \times D_{c,m}$$



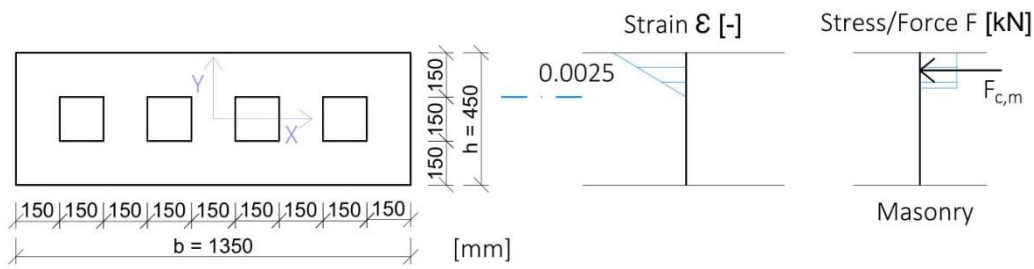
X - Plastic Centroid

$D_{c,m}$ – Lever Arm [m]

- $M = 503,01\text{kN} \times \left(\frac{0,45\text{m}}{2} - \frac{0,8 \times 0,225\text{m}}{2} \right) =$

$$= 67,906 \text{ [kNm]}$$

4. Point 3 – 2nd border of C-S change



4.1. Normal Force

$$N = F_{c,m}$$

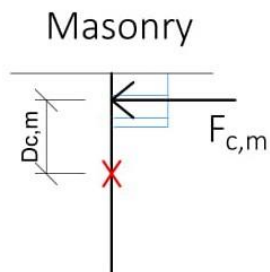
$$F_{c,m} = 0,8 \times (b \times (h - 0,3 \text{ m})) \times f_d \text{ [kN]}$$

- $$N = 0,8 \times (1,35\text{m} \times (0,45\text{m} - 0,3\text{m})) \times 2,43 \times 10^3 \text{ kPa} =$$

$$= 393,66 \text{ [kN]}$$

4.2. Moment

$$M = F_{c,m} \times D_{c,m}$$



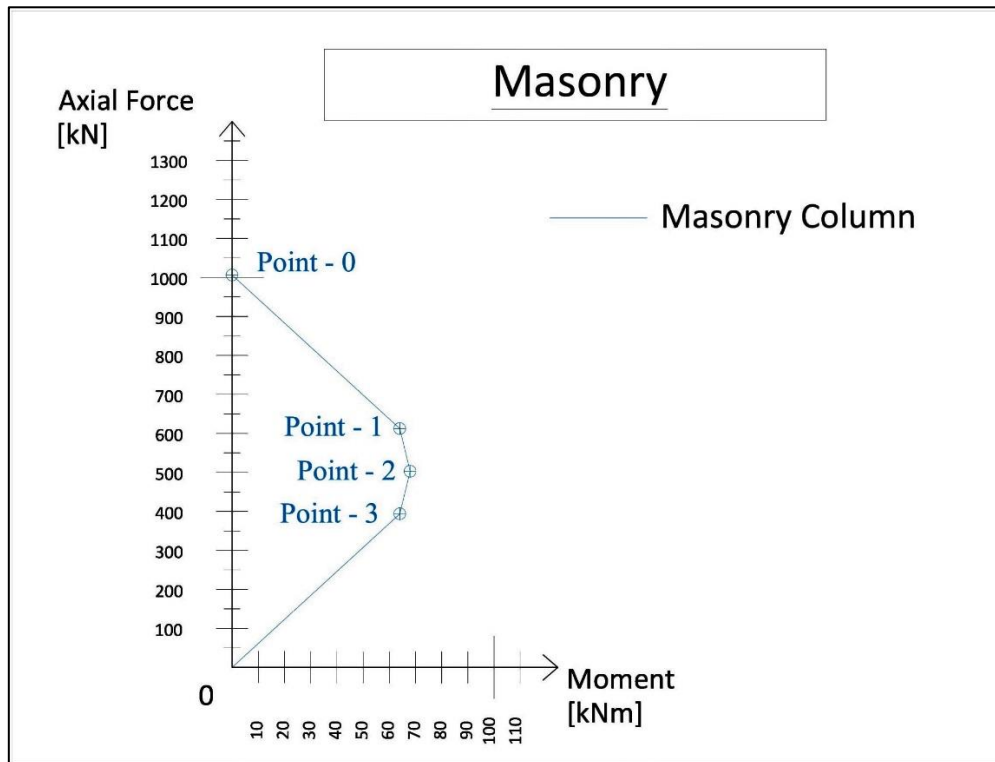
X - Plastic Centroid

$D_{c,m}$ – Lever Arm [m]

- $$M = 393,66\text{kN} \times \left(\frac{0,45\text{m}}{2} - \frac{0,8 \times 0,15\text{m}}{2} \right) =$$

$$= 64,954 \text{ [kNm]}$$

From these calculations we receive the following I.D. (as shown on the Pic. 34.)



(Pic. 34. Interaction Diagram of Masonry Chimney.)

3.1.2. Interaction Diagram of Masonry Chimney with Concrete (increase of L-C)

Interaction Diagram - Masonry Chimney with Concrete fill

Further step is to calculate the I.D. of RMC with concrete in the specific channel.

Compressive Strength of Concrete

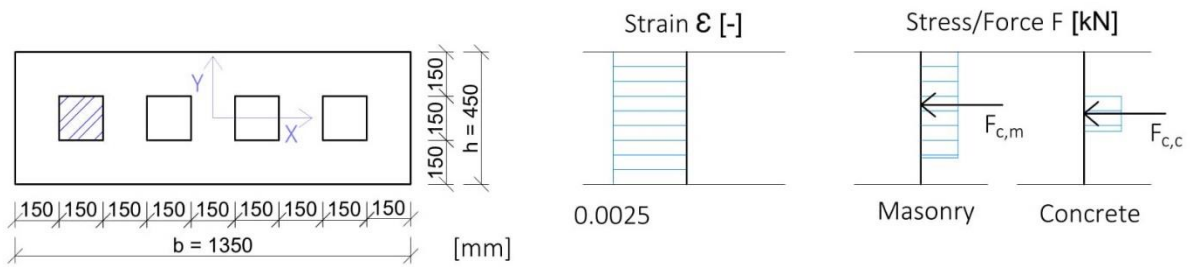
$f_{ck} = 20$ [MPa] - Characteristic Compressive Strength of the Concrete

$f_{cd} = \frac{f_{ck}}{\gamma_C}$ [MPa] – Design Compressive Strength of the Concrete

γ_C – partial safety factor for concrete = 1,5, EN.1992.1.1.2004 - 2.4.2.4 Table 2.1N

$$f_{cd} = \frac{f_{ck}}{\gamma_C} = \frac{20}{1,5} = 13,333 \text{ [MPa]}$$

1. Point 0 – Pure Compression



1.1. Normal Force

$$N = F_{c,m} + F_{c,c}$$

$$F_{c,m} = 0,8 \times (b \times h - 4 \times 0,15^2 \text{ m}^2) \times f_d \text{ [kN]}, F_{c,c} = 0,8 \times (0,15^2 \text{ m}^2) \times f_{cd} \text{ [kN]}$$

- $N = 0,8 \times (1,35\text{m} \times 0,45\text{m} - 4 \times 0,15\text{m} \times 0,15\text{m}) \times 2,43 \times 10^3 \text{ kPa} +$

$$+ 0,8 \times (0,15\text{m} \times 0,15\text{m}) \times 13,333 \times 10^3 \text{ kPa} =$$

$$= 1246,014 \text{ [kN]}$$

1.2. Moment

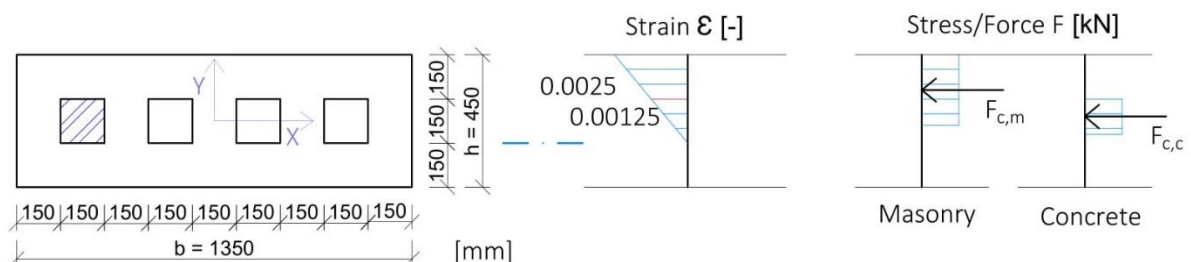
- $M = F_{c,m} \times D_{c,m} + F_{c,c} \times D_{c,c}$

$$M = 0 \text{ [kNm]}$$

1.3. Plastic Centroid (P.C.)

P.C. is in the middle because the C-S is symmetric. Thus, there is no Lever Arm for the Moment in this case.

2. Point 1 – 1st border of C-S change



2.1. Normal Force

$$N = F_{c,m} + F_{c,c}$$

$$F_{c,m} = 0,8 \times (b \times (h - 0,15m) - 4 \times 0,15^2 \text{ m}^2) \times f_d \text{ [kN]}$$

$$F_{c,c} = 0,8 \times (0,15^2 \text{ m}^2) \times f_{cd} \text{ [kN]}$$

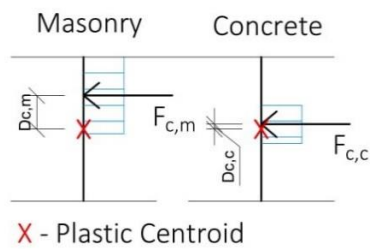
- $N = 0,8 \times (1,35m \times (0,45m - 0,15m) - 4 \times 0,15m \times 0,15m) \times 2,43 *$

$$* 10^3 \text{ kPa} + 0,8 \times (0,15m \times 0,15m) \times 13,333 \times 10^3 \text{ kPa} =$$

$$= 852,354 \text{ [kN]}$$

2.2. Moment

$$M = F_{c,m} \times D_{c,m} + F_{c,c} \times D_{c,c}$$



$D_{c,m}$ – Lever Arm [m]

$D_{c,c}$ – Lever Arm [m]

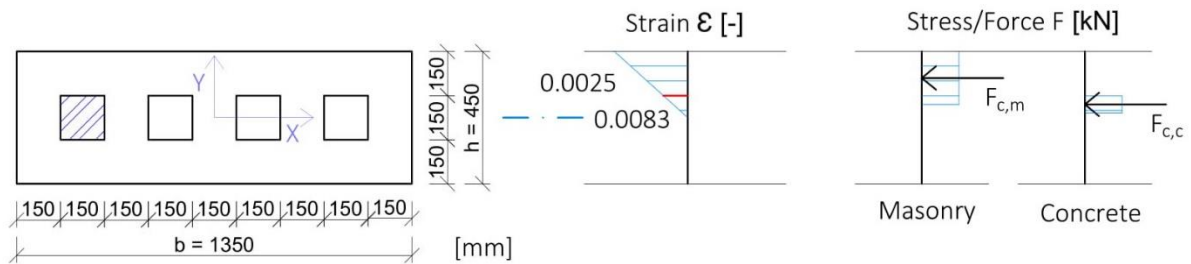
- $M = 612,36\text{kN} \times \left(\frac{0,45m}{2} - \frac{0,8 \times 0,3m}{2}\right) + 239,994\text{kN} \times \left(\frac{0,45m}{2} - \frac{0,8 \times 0,15m}{2} + 0,15m\right) =$

$$= 67,898 \text{ [kNm]}$$

2.3. Strain at Concrete

$$\epsilon_c = \frac{0,0025 \times 0,15m}{0,3m} = 0,00125 \text{ [-]}$$

3. Point 2 – Centre of C-S



3.1. Normal Force

$$N = F_{c,m} + F_{c,c}$$

$$F_{c,m} = 0,8 \times (b \times (h / 2) - (4 \times 0,15^2 \text{ m}^2) / 2) \times f_d \text{ [kN]}$$

$$F_{c,c} = 0,8 \times ((0,15^2 \text{ m}^2) / 2) \times f_{cd} \text{ [kN]}$$

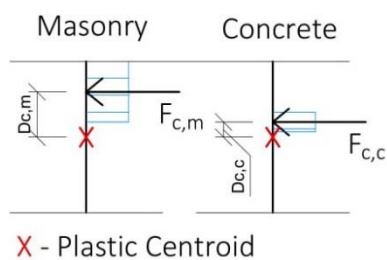
- $$N = 0,8 \times (1,35\text{m} \times (0,45\text{m} - 0,225\text{m}) - (4 \times 0,15\text{m} \times 0,15\text{m}) / 2) \times 2,43 \times 10^3 \text{ kPa} +$$

$$+ 0,8 \times (0,15^2 \text{ m}^2 / 2) \times 13,333 \times 10^3 \text{ kPa} =$$

$$= 623,007 \text{ [kN]}$$

3.2. Moment

$$M = F_{c,m} \times D_{c,m} + F_{c,c} \times D_{c,c}$$



$D_{c,m}$ – Lever Arm [m]

$D_{c,c}$ – Lever Arm [m]

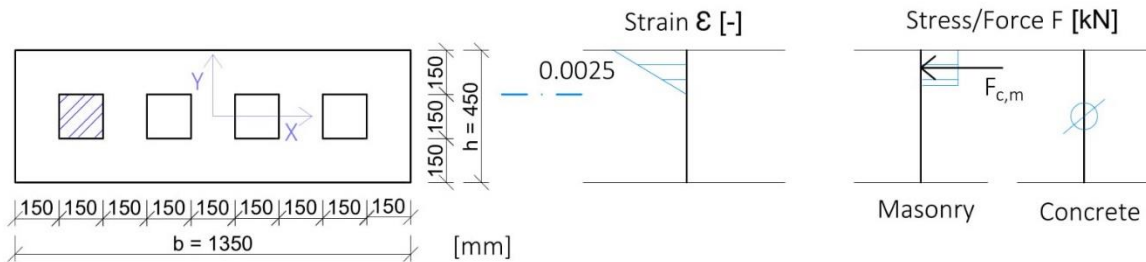
- $$M = 503,01\text{kN} \times \left(\frac{0,45\text{m}}{2} - \frac{0,8 \times 0,225\text{m}}{2} \right) + 119,997\text{kN} \times \left(\frac{0,15\text{m}}{2} - \frac{0,8 \times 0,15\text{m}}{4} \right) =$$

$$= 73,306 \text{ [kNm]}$$

3.3. Strain at Concrete

$$\epsilon_c = \frac{0,0025 \times 0,075\text{m}}{0,225\text{m}} = 0,00083 \text{ [-]}$$

4. Point 3 – 2nd border of C-S change



4.1. Normal Force

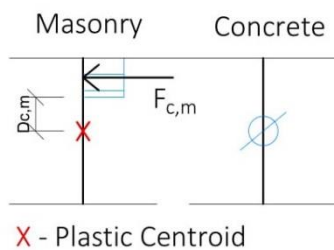
$$N = F_{c,m} + F_{c,c}$$

$$F_{c,m} = 0,8 \times (b \times (h - 0,3 \text{ m})) \times f_d \text{ [kN]}, F_{c,c} = 0 \text{ [kN]}$$

- $$N = 0,8 \times (1,35\text{m} \times (0,45\text{m} - 0,3\text{m})) \times 2,43 \times 10^3 \text{ kPa} + 0 \text{ kPa} = 393,66 \text{ [kN]}$$

4.2. Moment

$$M = F_{c,m} \times D_{c,m} + F_{c,c} \times D_{c,c}$$



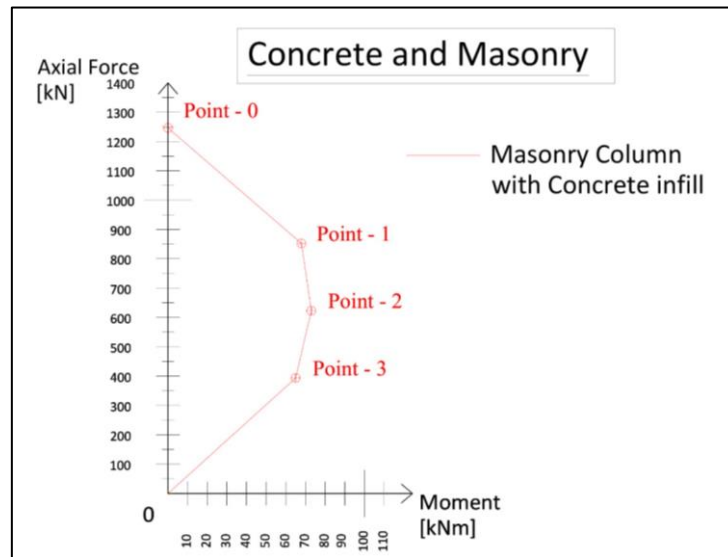
$D_{c,m}$ – Lever Arm [m]

$D_{c,c}$ – Lever Arm [m]

- $$M = 393,66\text{kN} \times \left(\frac{0,45\text{m}}{2} - \frac{0,8 \times 0,15\text{m}}{2} \right) + 0 \text{ kPa} =$$

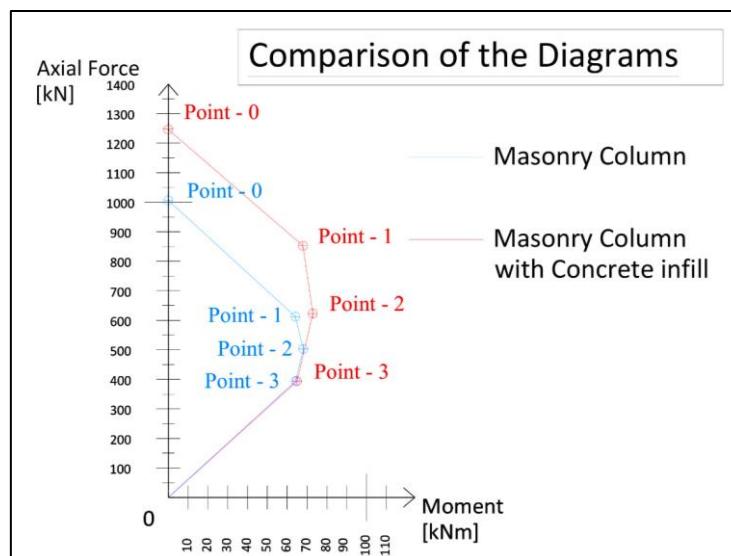
= 64,954 [kNm]

The result of these calculations we draw on the following I.D. (as shown on the Pic. 35.)



(Pic. 35. Interaction Diagram of Masonry Chimney with Concrete infill.)

3.1.3. Comparison of obtained I.D. (increase of L-C)

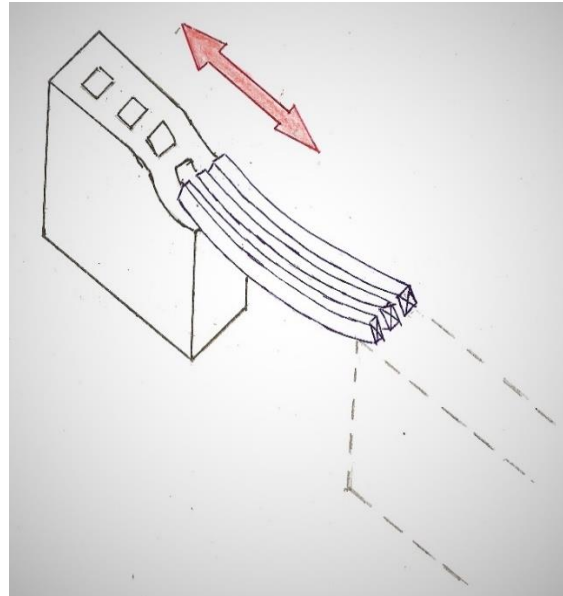


(Pic. 36. Combination of I.D.)

As we can observe from resulted diagrams, we achieved the strengthening of the Chimney to some extent. The improvement received in resistance of axial loading to the column. In tension there is no significant improvement, because the Concrete is not tensile material, as a result it increases the overall compressive strength of Reinforced Masonry Chimney.

3.2. Creating the Support for installation of Lintels

A further aspect of Reinforced Chimney with Concrete fill is creating the robust support structure for future lintels, which will be installed later. According to that target, we assess the working direction along the longitudinal side of the Chimney (Fig. 37). The eccentricity will appear on this line due to the local loading from lintels to our destined support.

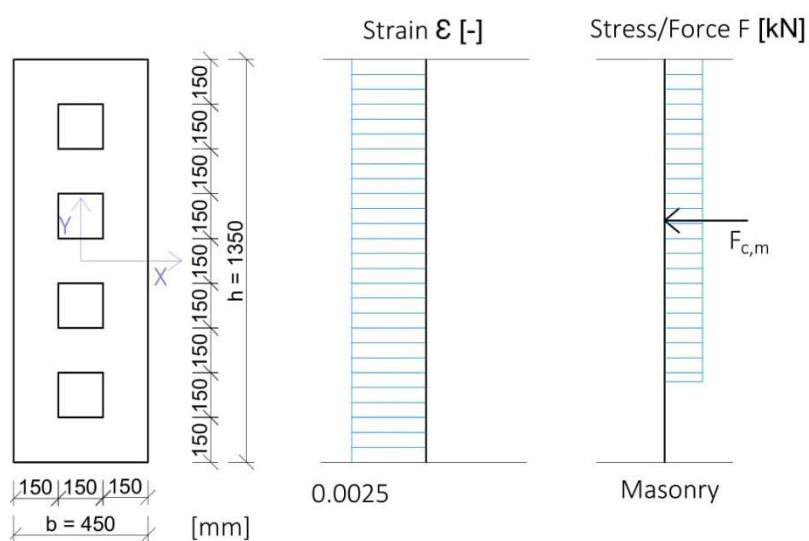


(Fig. 37. Behaviour of the Chimney under the loading.)

3.2.1. Calculation of Interaction Diagram of Masonry Chimney (Support)

Interaction Diagram – Masonry Chimney

1. Point 0 – Pure Compression



1.1. Normal Force

$$N = F_{c,m}$$

$$F_{c,m} = 0,8 \times (b \times h - 4 \times 0,15^2 \text{ m}^2) \times f_d \text{ [kN]}$$

- $$N = 0,8 \times (1,35\text{m} \times 0,45\text{m} - 4 \times 0,15\text{m} \times 0,15\text{m}) \times 2,43 \times 10^3 \text{ kPa} =$$

$$= 1006,02 \text{ [kN]}$$

1.2. Moment

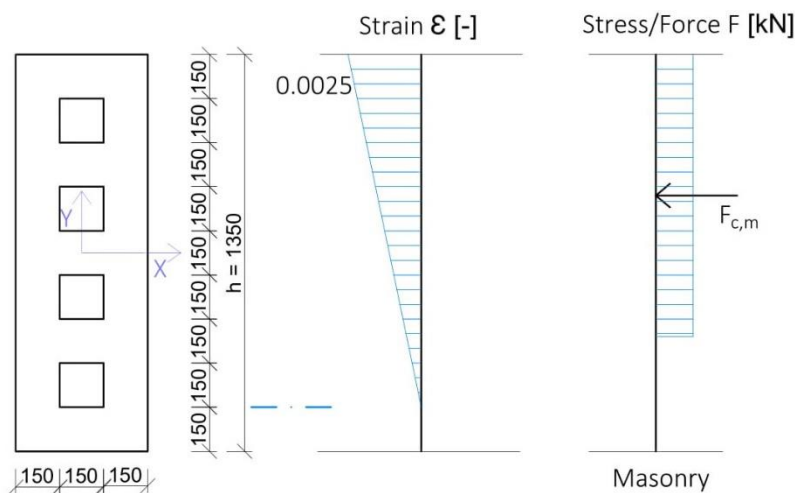
$$M = F_{c,m} \times D_{c,m}$$

- $$M = 0 \text{ [kNm]}$$

1.3. Plastic Centroid (P.C)

P.C. is in the middle because the C-S is symmetric. Thus, there is no Lever Arm for the Moment in this case.

2. Point 1 – 1st border between materials



2.1. Normal Force

$$N = F_{c,m}$$

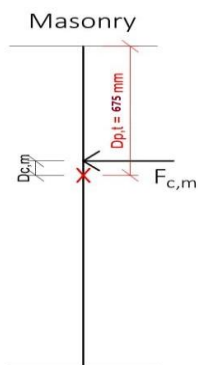
$$F_{c,m} = 0,8 \times (b \times (h - 0,15m) - 4 \times 0,15^2 \text{ m}^2) \times f_d \text{ [kN]}$$

- $$N = 0,8 \times (0,45m \times (1,35m - 0,15m) - (4 \times 0,15m \times 0,15m)) \times 2,43 \times 10^3 \text{ kPa} =$$

$$= 874,8 \text{ [kN]}$$

2.2. Moment

$$M = F_{c,m} \times D_{c,m}$$



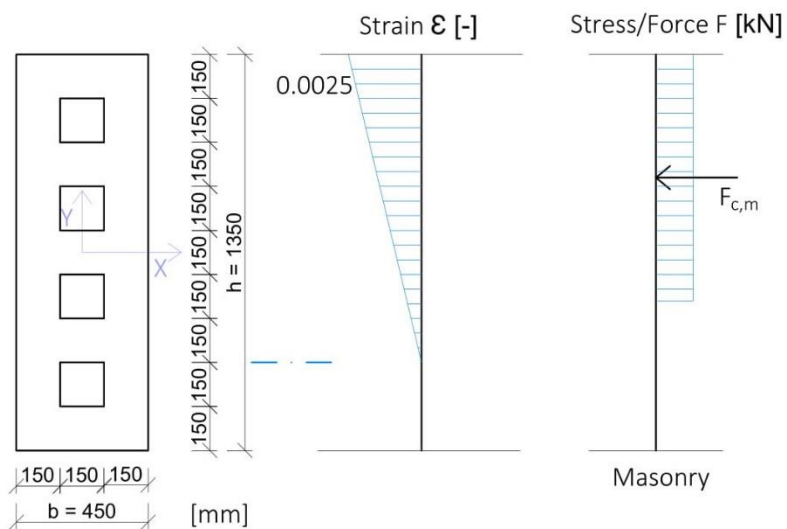
X - Plastic Centroid

$D_{c,m}$ – Lever Arm [m]

- $$M = 874,8 \text{ kN} \times (0,675m - 0,48m) =$$

$$= 170,586 \text{ [kNm]}$$

3. Point 2 – 2nd border between materials



3.1. Normal Force

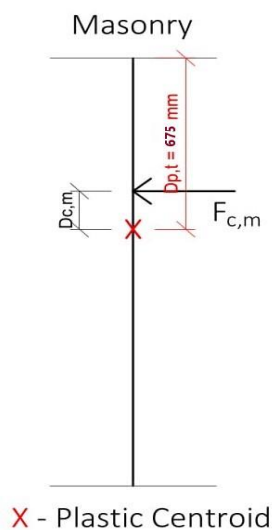
$$N = F_{c,m}$$

$$F_{c,m} = 0,8 \times (b \times (h - 0,3m) - 3 \times 0,15^2 \text{ m}^2) \times f_d \text{ [kN]}$$

- $N = 0,8 \times (0,45m \times (1,35m - 0,3m) - (3 \times 0,15m \times 0,15m)) \times 2,43 \times 10^3 \text{ kPa} =$
 $= 787,32 \text{ [kN]}$

3.2. Moment

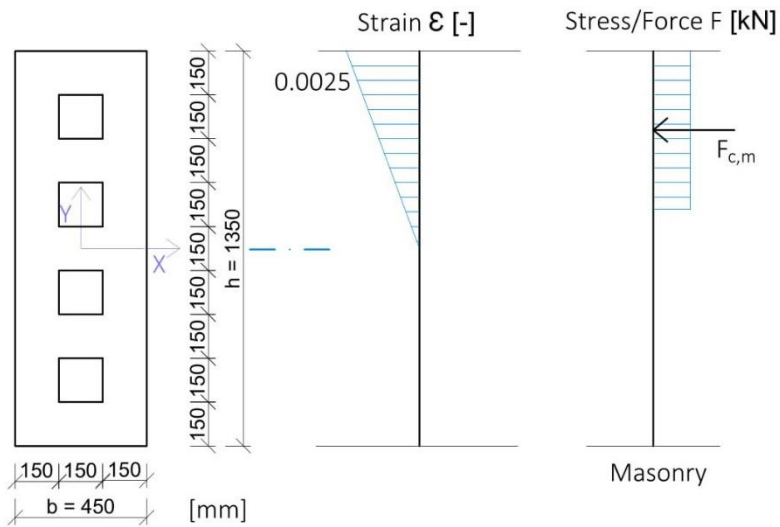
$$M = F_{c,m} \times D_{c,m}$$



$D_{c,m}$ – Lever Arm [m]

- $M = 787,32 \text{ kN} \times \left(\frac{1,35m}{2} - 0,8 \times \frac{1,05}{2} \right) =$
 $= 200,767 \text{ [kNm]}$

4. Point 3 – Centre of C-S



4.1. Normal Force

$$N = F_{c,m}$$

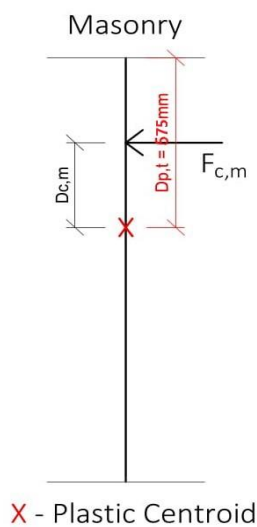
$$F_{c,m} = 0,8 \times (b \times (h / 2) - 2 \times 0,15^2 \text{ m}^2) \times f_d \text{ [kN]}$$

- $$N = 0,8 \times (0,45\text{m} \times (1,35\text{m} / 2) - (2 \times 0,15\text{m} \times 0,15\text{m})) \times 2,43 \times 10^3 \text{ kPa} =$$

$$= 503,01 \text{ [kN]}$$

4.2. Moment

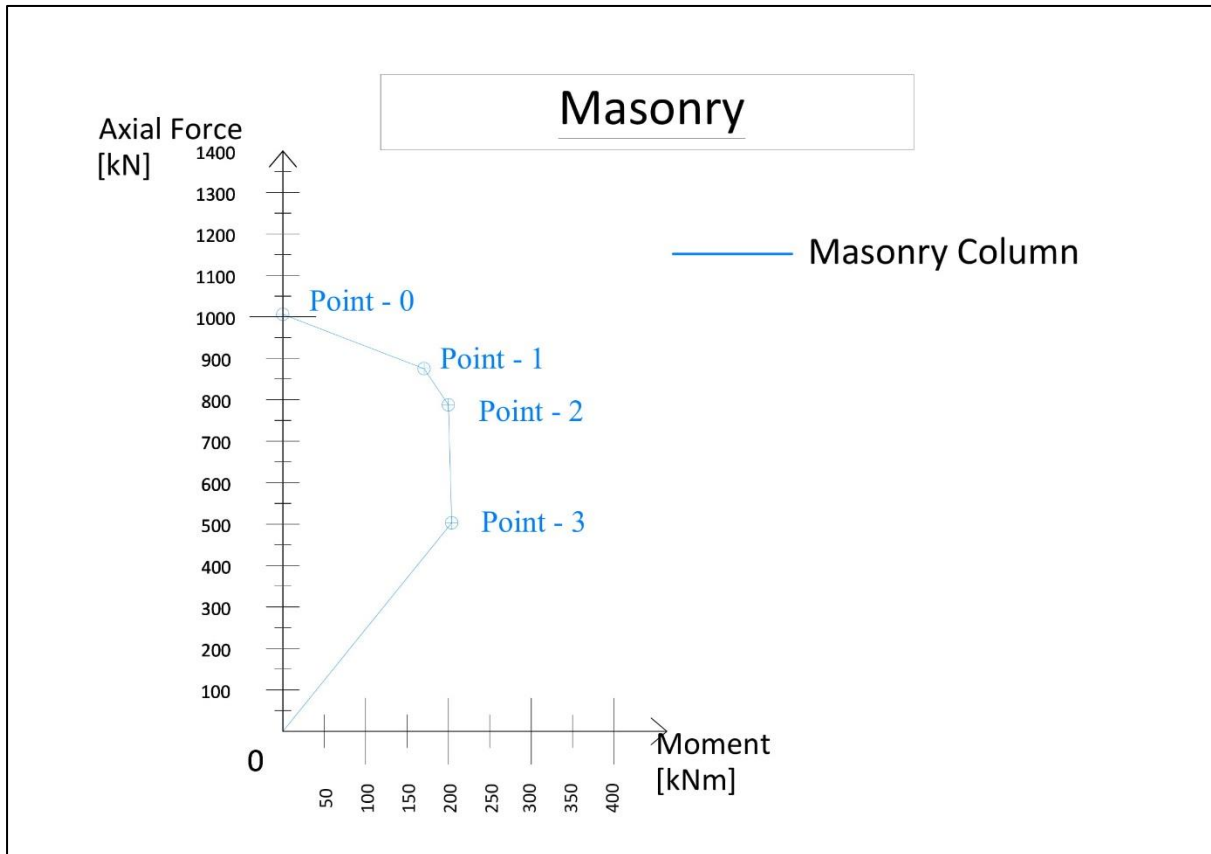
$$M = F_{c,m} \times D_{c,m}$$



$D_{c,m}$ – Lever Arm [m]

- $M = 503,01 \text{ kN} \times \left(\frac{1,35 \text{ m}}{2} - \frac{0,8 \times 0,675}{2} \right) =$
 $= 271,625 \text{ [kNm]}$

The result of these calculations we draw on the following I.D. (as shown on the Pic. 38.)



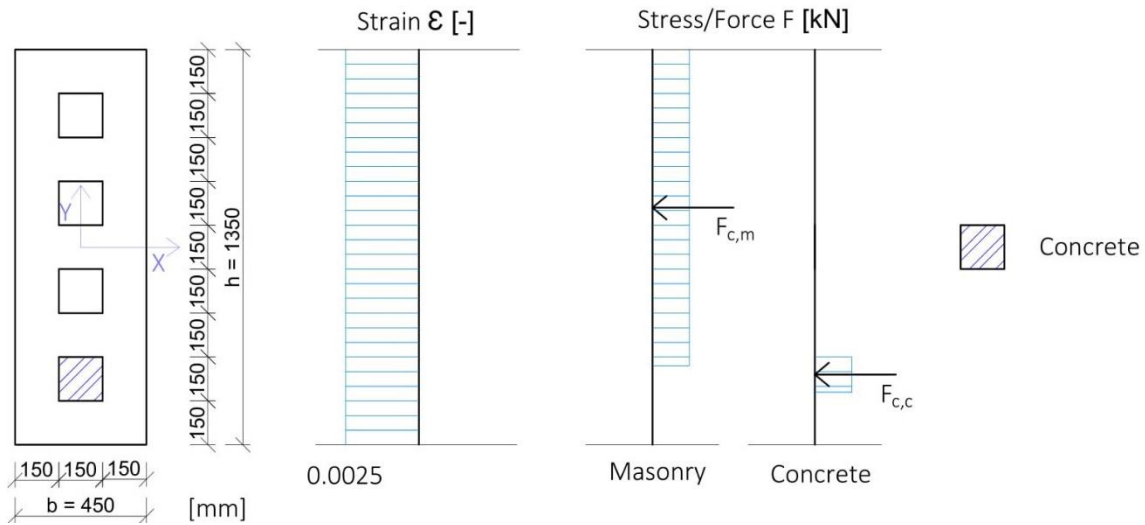
(Pic. 38. Interaction Diagram of Masonry Chimney with Concrete infill.)

The difference between diagram in the case of Overall load-bearing capacity and this case is that the moment is increased, because of increasing of lever arms in Bending Moment calculations (the cross-section is rotated from the previous case by 90 degrees).

3.2.2. Calculation of Interaction Diagrams

Interaction Diagram – Masonry Chimney with Concrete fill (Lintel design)

1. Point 0 – Pure Compression



1.1. Normal Force

$$N = F_{c,m} + F_{c,c}$$

$$F_{c,m} = 0,8 \times (b \times h - 4 \times 0,15^2 \text{ m}^2) \times f_d \text{ [kN]}, F_{c,c} = 0,8 \times (0,15^2 \text{ m}^2) \times f_{cd} \text{ [kN]}$$

- $$N = 0,8 \times (1,35\text{m} \times 0,45\text{m} - 4 \times 0,15\text{m} \times 0,15\text{m}) \times 2,43 \times 10^3 \text{ kPa} + 0,8 \times$$

$$\times (0,15\text{m} \times 0,15\text{m}) \times 13,333 \times 10^3 \text{ kPa} =$$

$$= 1246,014 \text{ [kN]}$$

1.2. Moment

$$M = F_{c,m} \times D_{c,m} + F_{c,c} \times D_{c,c}$$

- $$M = 0 \text{ [kNm]}$$

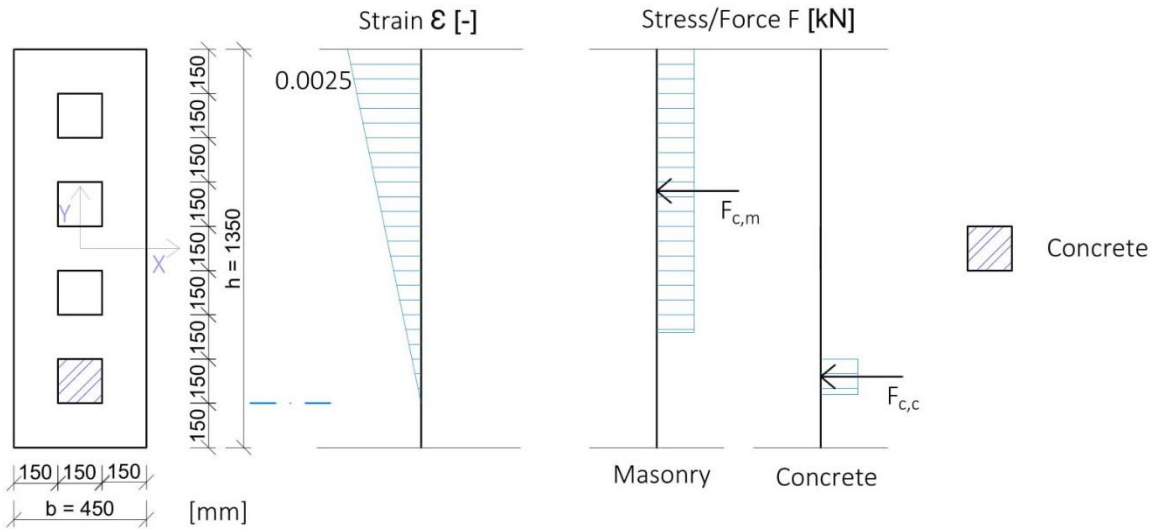
1.3. Plastic Centroid (P.C)

$$D_{p,t} = \frac{\sum F_i \times d_i}{\sum F_i}$$

- $$D_{p,t} = \frac{1006,02\text{kN} \times 0,675\text{m} + 239,999\text{kN} \times 1,125\text{m}}{1246,014\text{kN}} =$$

$$= 0,762 \text{ [m]}$$

2. Point 1 – 1st border between materials



2.1. Normal Force

$$N = F_{c,m} + F_{c,c}$$

$$F_{c,m} = 0,8 \times (b \times (h - 0,15m) - 4 \times 0,15^2 \text{ m}^2) \times f_d \text{ [kN]}, F_{c,c} = 0,8 \times (0,15^2 \text{ m}^2) \times f_{cd} \text{ [kN]}$$

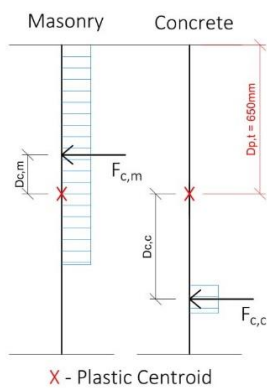
- $$N = 0,8 \times (0,45m \times (1,35m - 0,15m) - (4 \times 0,15m \times 0,15m)) \times 2,43 \times 10^3 \text{ kPa} +$$

$$+ 0,8 \times (0,15m \times 0,15m) \times 13,333 \times 10^3 \text{ kPa} =$$

$$= 1114,794 \text{ [kN]}$$

2.2. Moment

$$M = F_{c,m} \times D_{c,m} + F_{c,c} \times D_{c,c}$$



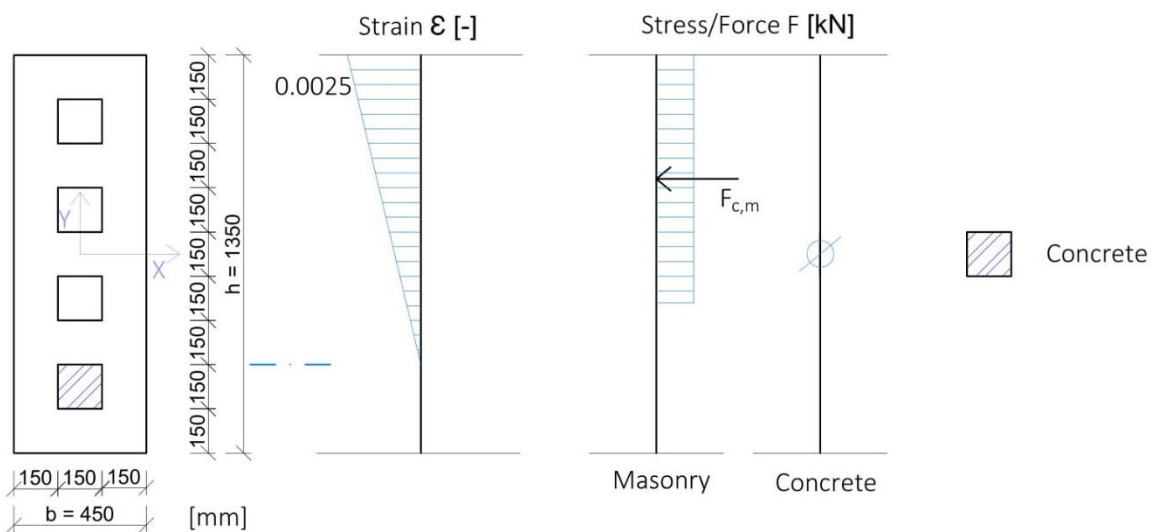
$D_{c,m}$ – Lever Arm [m]

$D_{c,c}$ – Lever Arm [m]

- $$M = 874,8\text{kN} \times (0,762\text{m} - 0,42\text{m}) + 239,994\text{kN} \times (0,762\text{m} - (1,05\text{m} + 0,8 \times 0,15\text{m} / 2)) =$$

$$= 215,664 \text{ [kNm]}$$

3. Point 2 – 2nd border between materials



3.1. Normal Force

$$N = F_{c,m} + F_{c,c}$$

$$F_{c,m} = 0,8 \times (b \times (h - 0,3\text{m}) - 3 \times 0,15^2 \text{ m}^2) \times f_d \text{ [kN]}, F_{c,c} = 0 \text{ [kN]}$$

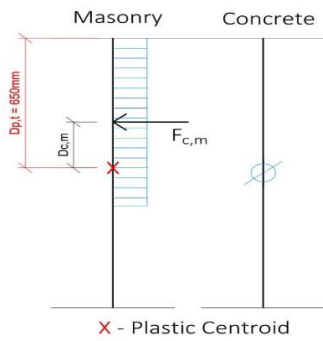
- $$N = 0,8 \times (0,45\text{m} \times (1,35\text{m} - 0,3\text{m}) - (3 \times 0,15\text{m} \times 0,15\text{m})) \times$$

$$\times 2,43 \times 10^3 \text{ kPa} + 0\text{kPa} =$$

$$= 787,32 \text{ [kN]}$$

3.2. Moment

$$M = F_{c,m} \times D_{c,m} + 0\text{kNm}$$



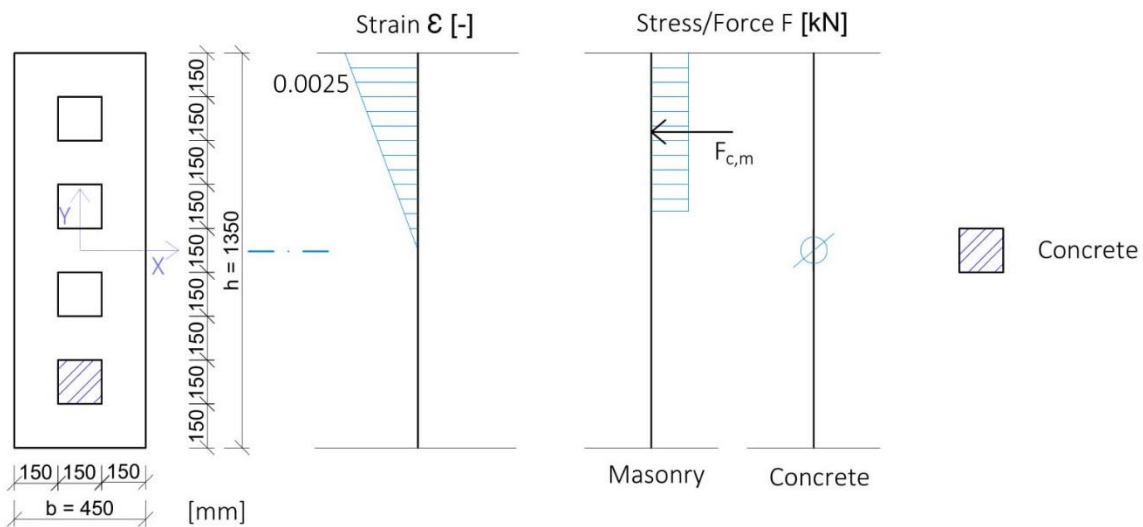
$D_{c,m}$ – Lever Arm [m]

$D_{c,c}$ – Lever Arm [m]

- $$M = 787,32 \text{ kN} \times \left(0,762 \text{ m} - 0,8 \times \frac{1,05}{2} \right) =$$

$$= 269,263 \text{ [kNm]}$$

4. Point 3 – Centre of C-S



4.1. Normal Force

$$N = F_{c,m} + F_{c,c}$$

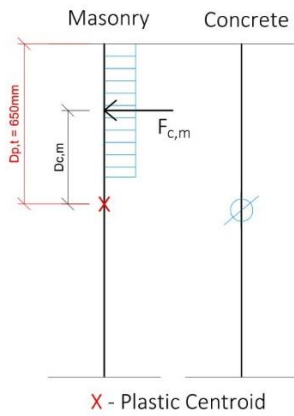
$$F_{c,m} = 0,8 \times (b \times (h / 2) - 2 \times 0,15^2 \text{ m}^2) \times f_d \text{ [kN]}, F_{c,c} = 0 \text{ [kN]}$$

- $$N = 0,8 \times (0,45 \text{ m} \times (1,35 \text{ m} / 2) - (2 \times 0,15 \text{ m} \times 0,15 \text{ m})) \times 2,43 \times 10^3 \text{ kPa} + 0 \text{ kPa} =$$

$$= 503,01 \text{ [kN]}$$

4.2. Moment

$$M = F_{c,m} \times D_{c,m} + 0 \text{ kNm}$$



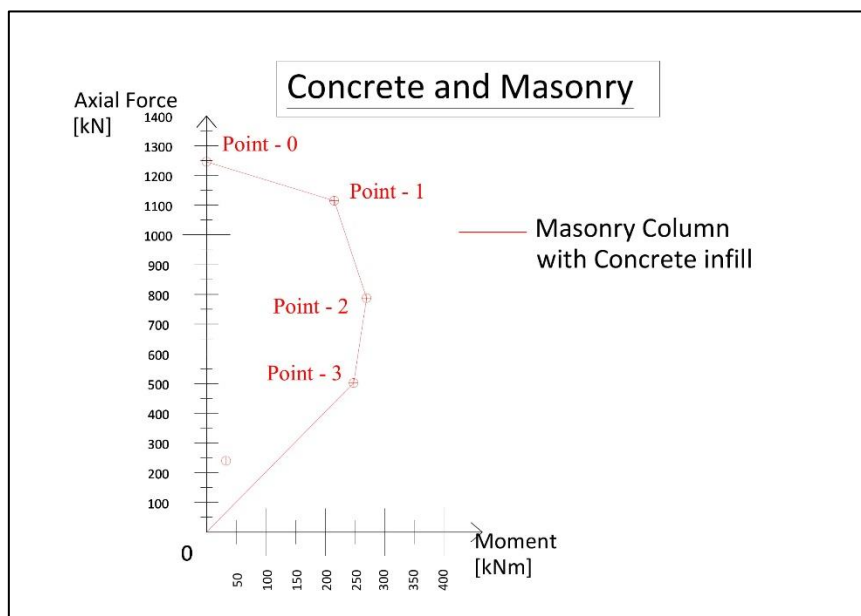
$D_{c,m}$ – Lever Arm [m]

$D_{c,c}$ – Lever Arm [m]

- $$M = 503,01 \text{ kN} \times (0,762 \text{ m} - 0,8 \times 1,35 \text{ m} / 4) + 0 \text{ kNm} =$$

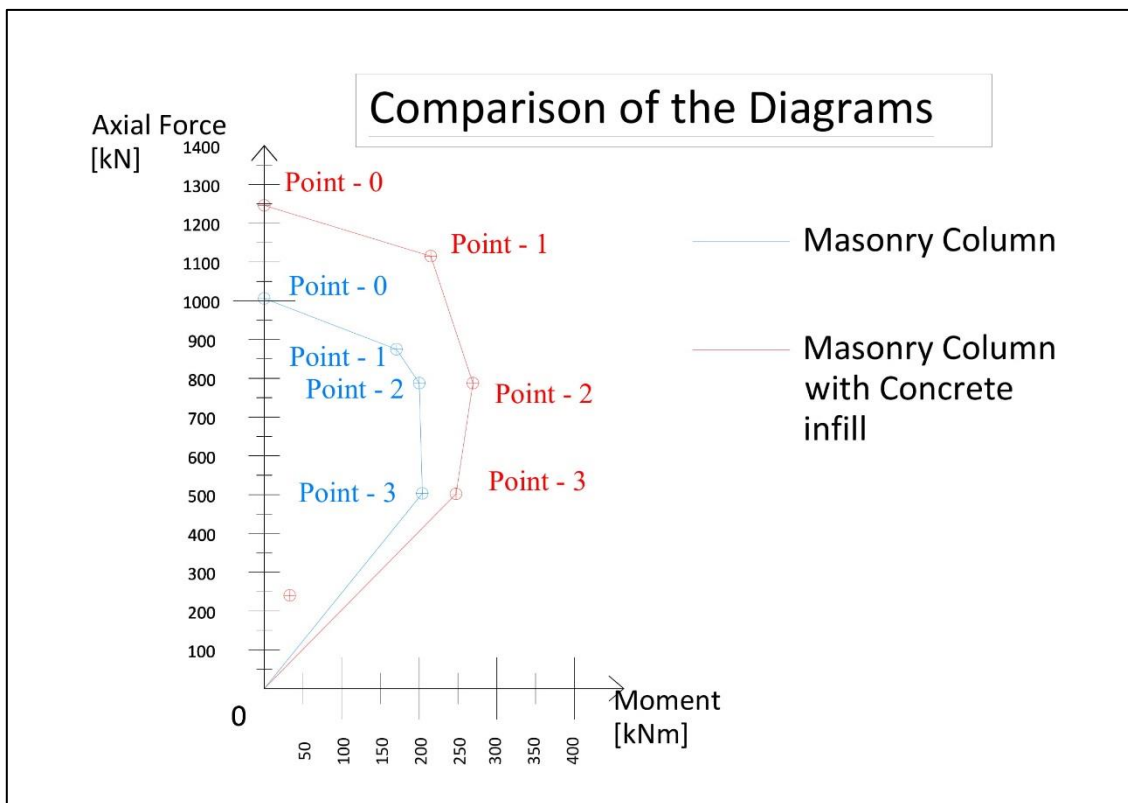
$$= 247,481 \text{ [kNm]}$$

The I.D. of Masonry with Concrete filling (see Fig. 39.)



(Fig. 39. Interaction Diagram of Masonry Chimney with Concrete filling.)

3.2.3. Comparison of obtained I.D. (increase of L-C)



(Fig. 40. Combinations of I.D.)

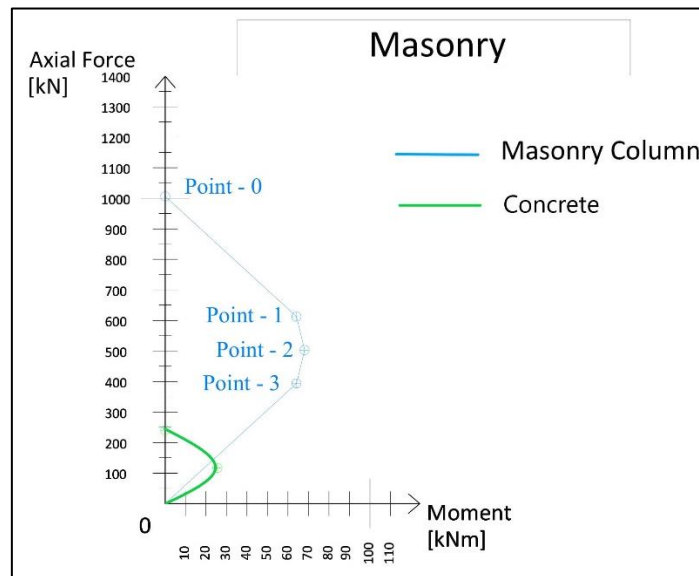
As it was mentioned in chapter 3.1.3, the total compressive strength of the RMC is increased with the help of Concrete. In addition to that, the modified column became less resistant to the tension or bending, because the Plastic Centroid of the column changed, due to the Concrete infill.

3.3. Potential issues influencing the Load-bearing function

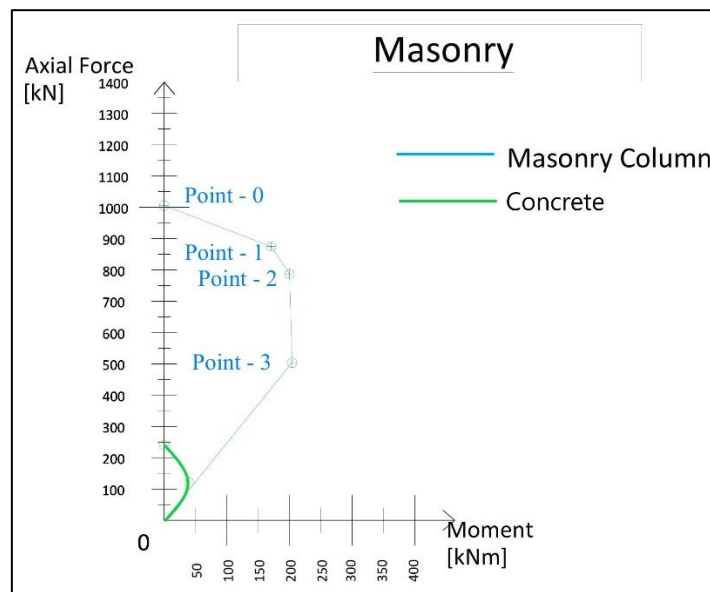
Let us consider the potential issues and see the appropriate results on the final graphs. There are two problems eventual problems as it was described in 2.2, one of them is soot and another is flexible tube inside the Chimney channel. On the Interaction Diagrams we will examine our issues.

- a) RMC with deposits of Soot on internal surfaces, but without the blockage of channel (see Pic.5). The remains of ash very, but in the mentioned paragraph 2.3 the preparation before concreting should include of cleaning up the soot, in the worst case of uncleaned channel the soot will work as separating layer, which will fail the bond between Masonry and Concrete as a consequence, the

deformation of Masonry and Concrete will be separate. In other words, we will receive Concrete column inside the Masonry Chimney (masonry column).



(Fig. 41. I.D of RMC with Soot. in the case of overall Load-bearing capacity)

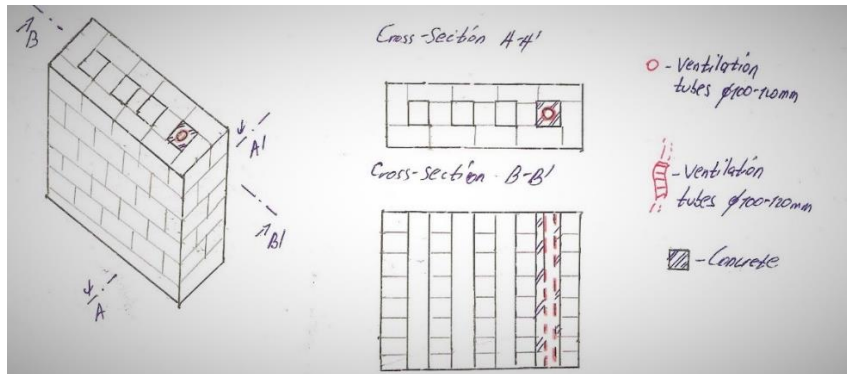


(Fig. 42. I.D of RMC with Soot. in the case of Lintel Support design)

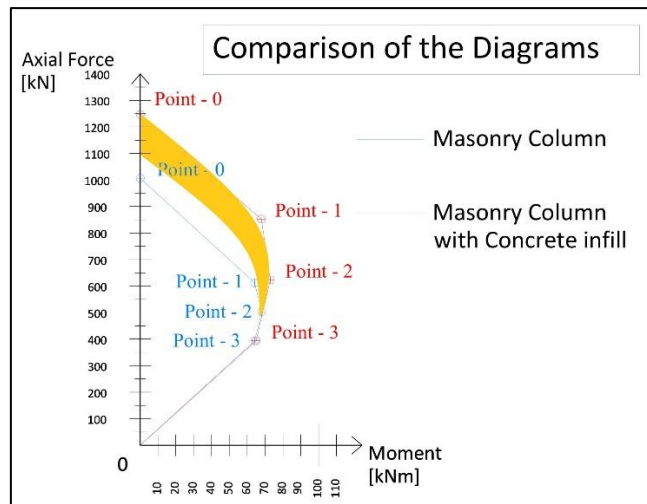
b) Ventilation Steel Tube is inside the chimney (shown Fig.43).

After the concreting the Chimney channel, in the case of no deposits of soot on the internal surfaces of the Chimney, we will receive two different Interaction Diagrams with respect to the future function of our ventilation shaft (chapter 2.3.2.2). The result vary between 95% to 70% of overall Load-capacity, because it depends on

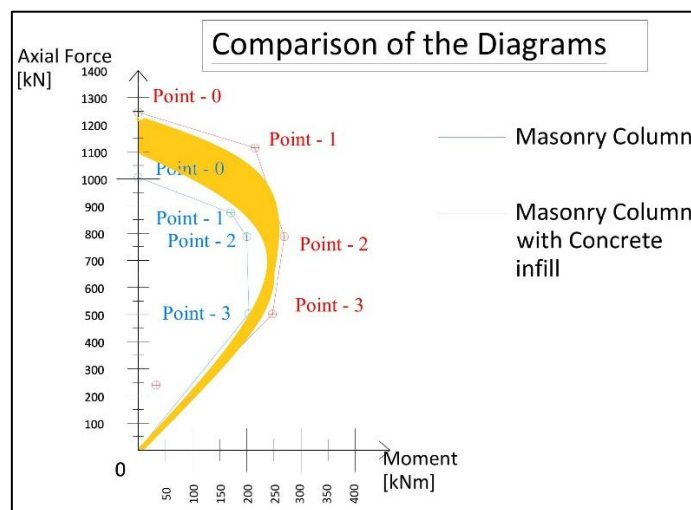
cross-sectional area of metal duct and condition, whether it is concreted inside or not, so it is recommended to concrete the shaft in any of these two cases.



(Pic. 43. Case of RMC with Concrete mixture and Steel ventilation tube inside.)



(Pic. 44. I.D of RMC with Vent Duct in the case of overall Load-bearing capacity.)



(Pic. 45. I.D of RMC with Vent Duct in the case of Lintel Support design.)

3.4. Creep and effect of age influencing the Load-bearing capacity

3.4.1. Construction Stages

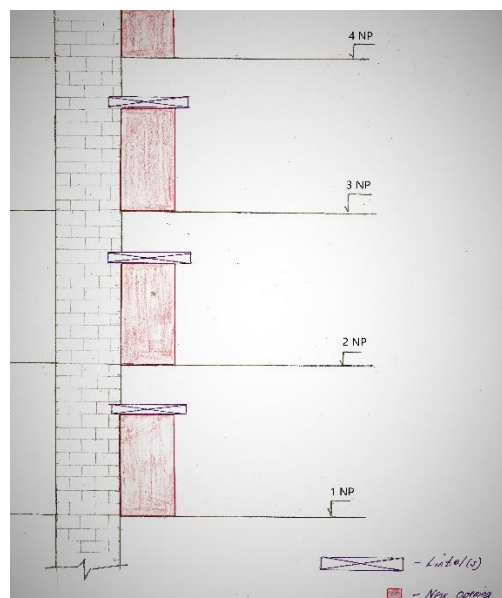
In this section 1 complete stage of installation the lintel(s) of one floor will be described. Further stages will be completely similar, for that reason there is no need to describe in this paper.

The main idea of installation the lintel(s) above any new doorway opening is to install mainly steel I or I+U profiles on one side (in our case one side and middle at once) of the wall, at least 1 day later from another side (see Photo 46).



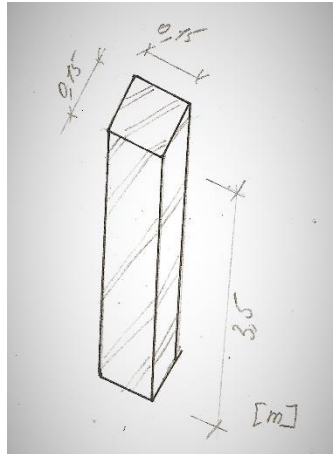
(Photo. 46. Insolation of lintel from one side.)

Let us assess overall static scheme of this specific reconstruction. In this research 4 floors of the given structure are considered. In all 4 levels the same doorways next to the Chimney were designed, accordingly we get the sketch (Fig. 47).



(Fig. 47. Sketch of lintel installation.)

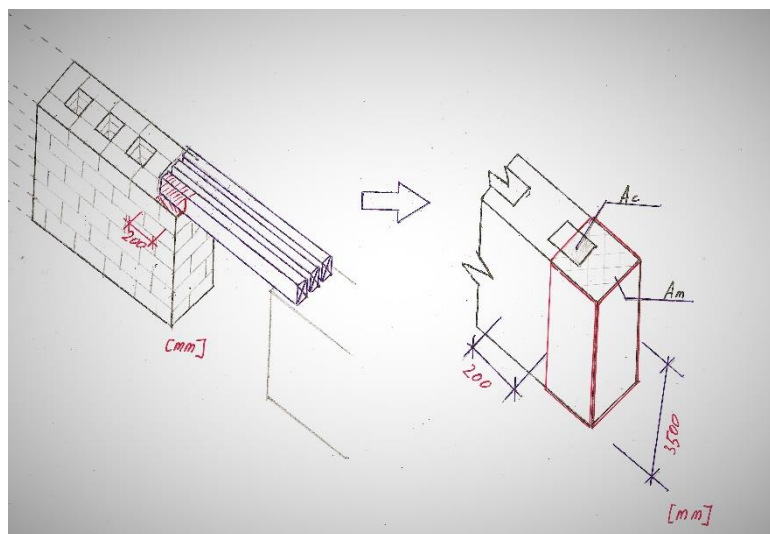
Corresponding to that we can simplify future concrete part of the composition just to the single column with height of 3.5 meters and cross-section 0,15 x 0,15 m² (as shown on the Picture 48). With the help of this model the calculation of creep and shrinkage will be more accurately defined with the help of Model B3.



(Picture. 48. Concrete Column inside Chimney Channel.)

The most loaded Concrete Column will be in the first floor, because it will support not only the service and dead-load from overall building (floors + walls structures), but also the self-weight of the concrete from top levels.

Similarly the Chimney “Column“ will be taken from the same level. All in all, the static scheme is presented below (see sketch 49).



(Sketch. 49. Static scheme of loaded RMC.)

Stage 1

First Stage consists of:

- 1) pouring the Concrete mixture to the level of the 2nd Ground Floor (GF) at the beginning of the working day.
- 2) Right after the that the vibration is proceeded. The Concrete is hardening and in 12 hours continuing the concreting up the 3rd Ground Floor in the end of working day.

Stage 2

Second Stage consists of:

- 1) New portion of Concrete is poured up to the 4th Ground Floor.
- 2) The last concreting stage is followed up to the Roof level.
- 3) Simultaneously the installation of Lintel(s) from 1 side is performed on the 1st and 2nd GF. We assume, that at this point (24 hours after pouring the fresh mixture) the newly installed Lintel(s) bear(s) the half of the loading from the structure on the RMC, the second half of the loading is transformed to the old structure (Masonry).

Stage 3

Third Stage consists of:

- 1) Installation of Lintels on the 1st and 2nd GF from other side
- 2) Installation of Lintels on 3rd and 4th GF from one side

Stage 4

Final Stage consists of:

- 1) Installing the last Lintels from second face of the wall on 3rd and 4th

3.4.2. Calculation of Creep and Damage

The following calculations depends on the age of Concrete; thus, the first point will be described in details. Other points will be shown in the tables and plotted on the final graphs.

3.4.2.1. Creep of Massonry

- Compressive Strength of Masonry Unit

$f_u = 15$ [MPa] - Mean Compressive Strength of the Brick

$f_m = 5$ [MPa] – Compressive Strength of the Mortar

$f_b = \eta \times \delta \times f_u$ [Mpa] – Normolised Mean Compressive Strength

$f_b = 1 \times 0,75 \times 15\text{Mpa} = 11,25$ [MPa]

$$f_k = K f_b^\alpha f_m^\beta \quad \text{Characteristic Compressive Strength of the Masonry}$$

K – coeff. depends on type of masonry unit and mortar = 0,55, EN.1996.1.1.2005 - Tab3.3

$f_k = 0,55 \times 11,25^{0,7} \text{ MPa} \times 5^{0,3} \text{ MPa} = 4,85$ [MPa]

$f_d = \frac{f_k}{\gamma_M}$ [MPa] – Design Compressive Strength of the Masonry Unit

γ_M – partial safety factor = 2

EN.1996.1.1.2005 - 2.4.3

$f_d = \frac{f_k}{\gamma_M} = \frac{4,85}{2} = 2,43$ [MPa]

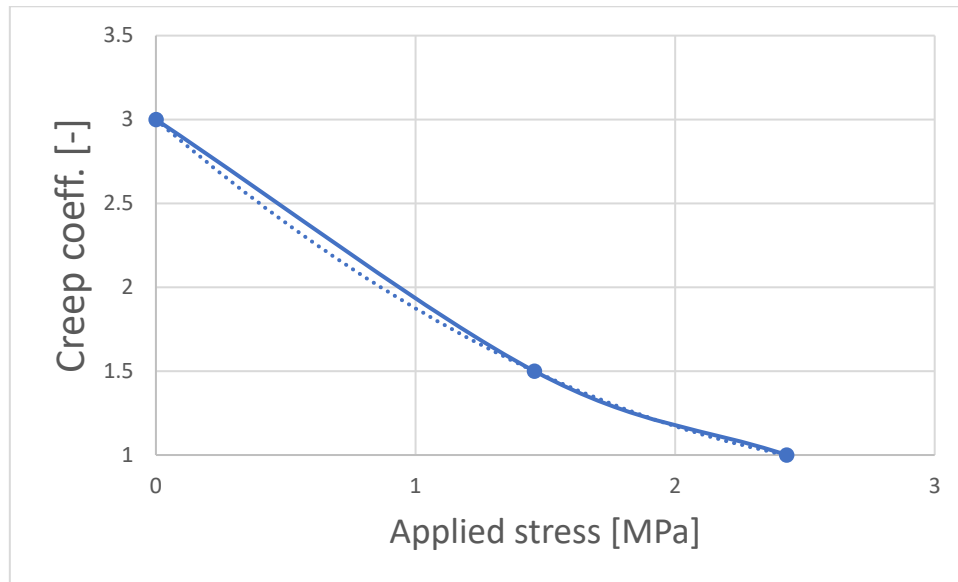
- Elastic Modulus of Masonry Unit

Elastic Modulus			
$E = K_E \cdot f_k$	$K_E =$	1000	for masonry from clay
$f_k =$	6	[Mpa]	
$E =$	6000	[Mpa]	

In our case, we have the historic building and the Elastic Modulus of Elasticity we consider to be at the maximum value. In other words, we neglect the age of Masonry Unit.

- Creep coefficient for single-leaf masonry walls

Coefficient vs. Applied stress (Chart 50).



(Chart 50. Creep Coefficient vs. Applied stress.)

3.4.2.2. Creep of Concrete

- Compressive Strength of Concrete

Concrete: C20/25

$f_{ck} = 20$ [MPa] - Characteristic Compressive Strength of the Concrete

$f_{cd} = \frac{f_{ck}}{\gamma_c}$ [MPa] – Design Compressive Strength of the Concrete

γ_c – partial safety factor for concrete = 1,5, EN.1992.1.1.2004 - 2.4.2.4 Table 2.1N

$$f_{cd} = \frac{f_{ck}}{\gamma_c} = \frac{20}{1,5} = 13,333 \text{ [MPa]}$$

- Creep and Shrinkage Prediction

First of all, the Elastic Modulus of the Young Concrete has to be calculated before any calculations of Creep and Shrinkage.

Our desire grade of Concrete is C20/25. In order to create this mixture we will use CEM 42.5 N; the ratio C:S:G is [1:2:4] (cement = 300 kg/m³; sand and gravel = 1800 kg/m³); w/c ratio is 0.6 (water = 180 kg/m³). The geometry of our Concrete Column in Masonry Chimney is shown on the picture 23.

- Variation of the modulus of elasticity with time can be estimated:

$$E_{cm}(t) = (f_{cm}(t)/f_{cm})^{0.3} E_{cm}$$

$$f_{cm} = 28 \text{ [MPa]}, E_{cm} = 30 \text{ [GPa]}$$

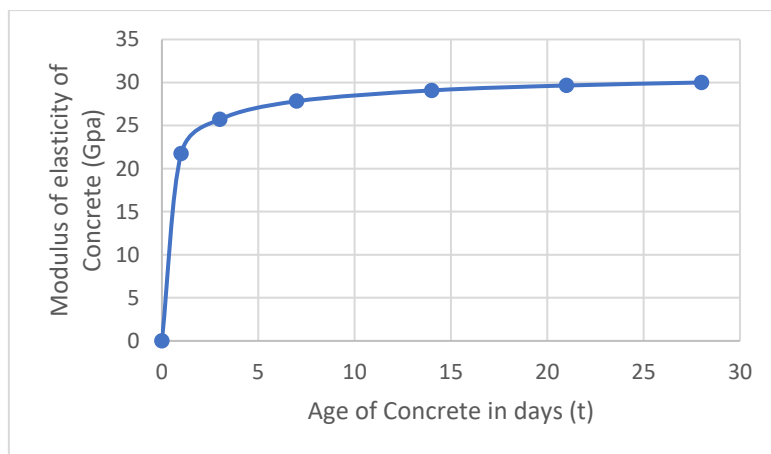
- $f_{cm}(t) = \beta_{cc}(t) \cdot f_{cm}$
- $\beta_{cc}(t) = \exp \{ s [1 - (28/t)^{1/2}] \}$

(t)	$\beta_{cc}(t) =$	$\beta_{cc}(t) = \exp \{ s [1 - (28/t)^{1/2}] \}$	
0	0		
1	0.342024	s =	a coefficient which depends on the type of cement:
3	0.59824	0.2	for CEM 42,5 R, CEM 52,5 N and CEM 52,5 R (Class R)
7	0.778801	0.25	for CEM 32,5 R and <u>CEM 42,5 N</u> (Class N)
14	0.901628	0.38	for CEM 32,5 N (Class S)
21	0.962063		
28	1		

(t)	$f_{cm}(t) =$	$f_{cm}(t) = \beta_{cc}(t) \cdot f_{cm}$
0	0	
1	9.57666	
3	16.75073	
7	21.80642	
14	25.24558	
21	26.93777	
28	28	

(t)	$E_{cm}(t) =$	$E_{cm}(t) = (f_{cm}(t)/f_{cm})^{0.3} E_{cm}$
0	0	
1	21.74393	
3	25.71485	
7	27.8323	
14	29.08235	
21	29.65394	
28	30	

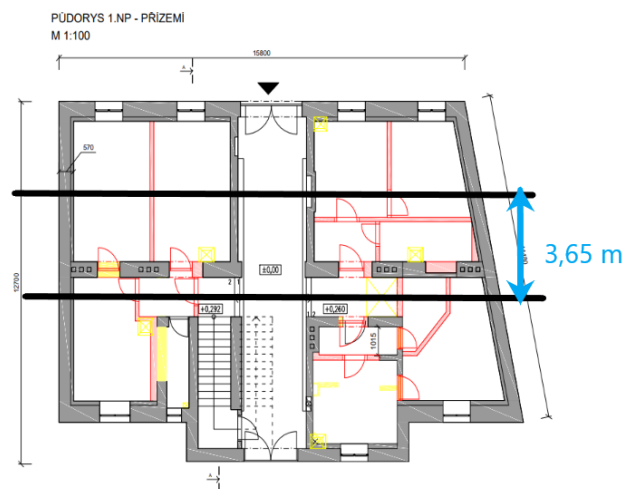
We can plot the graph of Modulus of Elasticity of Concrete to Age of it (chart 51).



(Fig. 51 Modulus of Elasticity of Concrete.)

- Calculation of Reaction Force in the RMC Support

First step is to calculate the load from the floor structure (Fig.52) and find the Reaction force for the desire RMC.



(Fig. 52. Load distribution to the load-bearing wall.)

Floor Structure

Name	Sizes		Dead-Load	Units
Concrete	150 mm	=	4.16	[kN/m ²]
Metalic Dek	ComFlor 46			
IPE-Beam	IPE-240	=	0.307	[kN/m]

IPE-240

Distribution of IPE profile to m²

Number of profiles = $(15\text{m}/1.5\text{m}) * 3.65\text{m} = 20$

IPE-240 Destribution per m² = $(3.65\text{m} * 20 * 0.307\text{kN/m}) / \text{A}[\text{m}^2] = 0.3686 \text{ kN/m}^2$

Calculation of Loads from floor structure from 1 floor

		Char.		Design
		kN/m ²	γ_F	kN/m ²
Dead Load				
	Other load	1.5		
	Self-weight	4.5286		
	$g = \Sigma$	6.0286	1.35	8.13861
Live Load				
	Floor	1.9		
	$q = \Sigma$	1.9	1.5	2.85
Total $gd+qd = \Sigma$		7.9286		10.9886

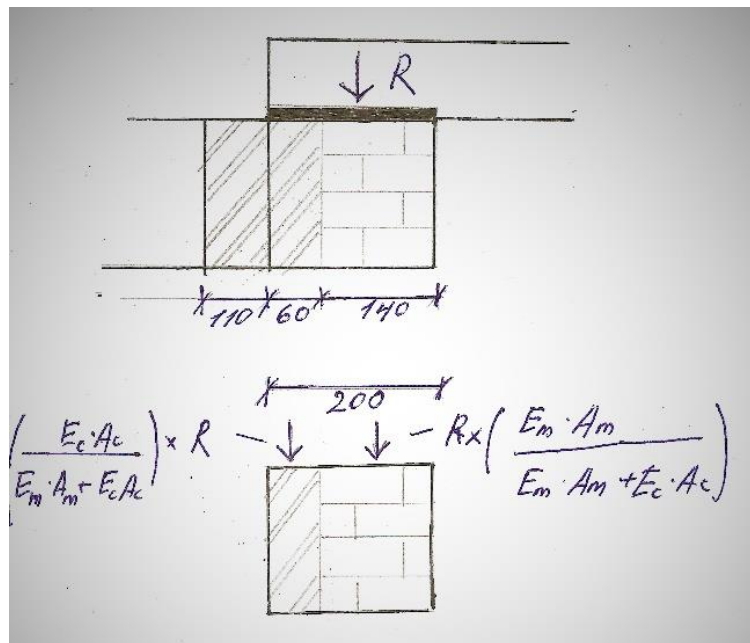
RMC weight (9m) = 13.689 kN

Reaction force to the RMC

$R = (gd+qd) * \text{Asup of RMC}$

The next step is to split the Reaction force between the Concrete and Masonry according to their stiffnesses (see sketch 53). This ratio will change with respect to age of Concrete and

changes in load distribution as these will affect long-term stiffness affected by creep of Masonry and Concrete.



(Sketch. 53.Split of Reaction Force.)

$$R_{\text{masonry}} = \left(\frac{E_m \cdot A_m}{E_m \cdot A_m + E_c \cdot A_c} \right) \cdot R$$

$$R_{\text{concrete}} = \left(\frac{E_c \cdot A_c}{E_m \cdot A_m + E_c \cdot A_c} \right) \cdot R$$

$$A_{\text{sup}} = 0.45\text{m} \cdot 0.2\text{m} = 0.09 \quad [\text{m}^2]$$

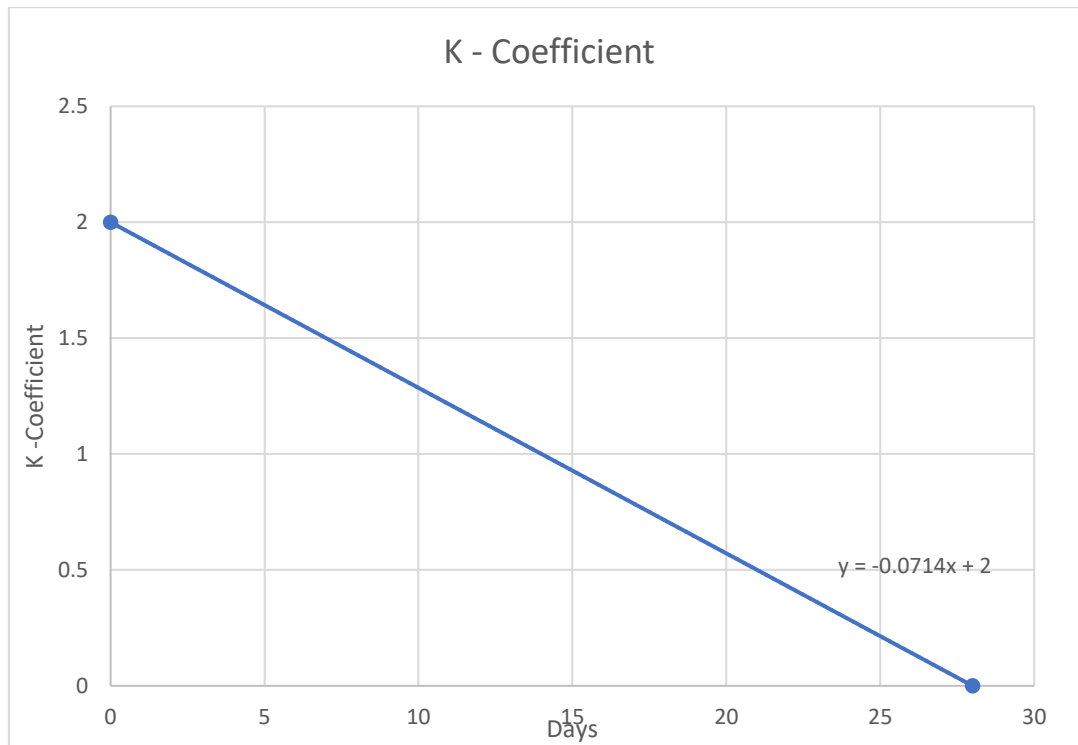
$$A_{\text{concrete, sup}} = 0.15\text{m} \cdot 0.06\text{m} = 0.009 \quad [\text{m}^2]$$

$$A_{\text{masonry, sup}} = (0.45\text{m} \cdot 0.2\text{m} - 0.15\text{m} \cdot 0.06\text{m}) = 0.081 \quad [\text{m}^2]$$

- Compliance function of Concrete

The further calculation of compliance function was made with the help of Excel according to Creep and Shrinkage Prediction Model for Analysis and Design of Concrete Structures: Model B3.

We will modify the Compliance function by introducing the coefficient K (see the following Picture 54). The coefficient K representing the age of Concrete, the younger the Concrete, the bigger the Creep of it, as the result it will affect the load-bearing distribution between masonry and Concrete. The K is the linear function, which will be divided by Compliance function of the Concrete.



(Sketch. 54.K coefficient.)

The following calculation of Compliance function will illustrate first point, further points will be calculated automatically and placed directly to the table and plotted on the graph.

- 0) Time zero ($t_0 = 0$), $E_{c,t0} = 0$ and $E_{m,t0} = 0$ used for load distribution calculation
- 1) Time One:

Creep of Concrete

- $t_1 = 1$ [day]
- $E_{c,t1} = E_{c,t0} - 1/\Delta C_{o,t1}$

where:

$$E_{c,t0} = 21,74393 \text{ [GPa]}$$

$$\Delta C_{o,t1} / K1 = 61,651 [1/MPa]$$

$\Delta C_{o,t1}$ – Calculated by Model B3

$$E_{c,t1} = 21,74393 \text{ GPa} - \frac{1}{61,651 \text{ GPa}} = 21,72771 [\text{GPa}]$$

Creep of Masonry

- $E_{m,t1} = \frac{E_{m,to}}{1+\phi_{m,t1}} [\text{GPa}]$

$\phi_{m,t1}$ - Calculated from (Chart 1. Creep Coefficient vs. Applied stress.)

- R [MN]
- $R_{masonry} = ((E_m * A_m) / (E_m * A_m + E_c * A_c)) * R [\text{MN}]$
- $\sigma_{m,t1} = \frac{R_{masonry}}{A_m} [\text{MPa}]$

where:

$$E_{m,to} = 6000 [\text{MPa}]$$

$$R = ((gd+qd) * A_{sup} \text{ of RMC}) + \text{Self-weight of Masonry Chimney}) * 5 \text{ floors} =$$

$$= ((10,9886 \text{ kN/m}^2 \times 0,09 \text{ m}^2) + (16 \text{ kN/m}^3 \times 0,081 \text{ m}^2)) \times 5 =$$

$$= 11,42487 \text{ kN} = 11,42487 \times 10^{-3} [\text{MN}]$$

$$R_{masonry} = \frac{E_{m,to} * A_m}{E_{m,to} * A_m + E_{c,t1} * A_c} \times R = \frac{6 \text{ GPa} \times 0,081 \text{ m}^2}{6 \text{ GPa} \times 0,081 \text{ m}^2 + 21,72771 \text{ GPa} \times 0,009 \text{ m}^2} *$$

$$* 11,42487 \times 10^{-3} \text{ MN} = 8,627 \times 10^{-3} [\text{MN}]$$

$$\sigma_{m,t1} = \frac{8,627 \times 10^{-3} \text{ MN}}{0,081 \text{ m}^2} = 0,10651 [\text{MPa}]$$

$$\phi_{m,t1} = 2,859955 [-]$$

$$E_{m,t1} = \frac{E_{m,to}}{1+\phi_{m,t1}} = \frac{6 \text{ GPa}}{1+2,859955} = 1,554422 \text{ [GPa]}$$

2) Time Two:

Creep of Concrete

- $t2 = (t1 + \Delta t)$
- $E_{c,t1} = 21,73552 \text{ [GPa]}$

where:

$$\Delta t = 0,5 \text{ [day]}$$

$$E_{c,t1} = 21,73552 \text{ [GPa]}$$

$$\Delta C_{o,t2} / K2 = 92,57753 \text{ [1/MPa]}$$

$\Delta C_{o,t2}$ - Calculated by Model B3

$$t2 = (1 + 0,5) = 1,5 \text{ [days]}$$

$$E_{c,t2} = 21,73552 \text{ GPa} - \frac{1}{175,24 \text{ GPa}} = 21,71691 \text{ [GPa]}$$

Creep of Masonry

- $E_{m,t2} = \frac{E_{m,to}}{1+\phi_{m,t2}} \text{ [GPa]}$
- $R \text{ [MN]}$
- $R_{masonry} = ((E_m * A_m) / (E_m * A_m + E_c * A_c)) * R \text{ [MN]}$
- $\sigma_{m,t2} = \frac{R_{masonry}}{A_m} \text{ [MPa]}$

where:

$$E_{m,to} = 6000 \text{ [MPa]}$$

R= (((gd+qd) *Asup of RMC+Self-weight of Masonry Chimney)*5floors + new level of Concrete) =

$$= (((10,9886 \text{ kN/m}^2 \times 0,09 \text{ m}^2) + (16 \text{ kN/m}^3 \times 0,081 \text{ m}^2)) \times 5) +$$

$$+ (25 \text{ kN/m}^3 \times 0,009 \text{ m}^2 \times 3\text{m}) \times 2\text{floors}) =$$

$$= 12,775 \text{ kN} = 12,775 \times 10^{(-3)} \text{ [MN]}$$

$$R_{\text{masonry}} = \frac{E_{m,t0} \cdot A_m}{E_{m,t0} \cdot A_m + E_{c,t2} \cdot A_c} \times R = \frac{6 \text{ GPa} \times 0,081 \text{ m}^2}{6 \text{ GPa} \times 0,081 \text{ m}^2 + 21,71691 \text{ GPa} \times 0,009 \text{ m}^2} *$$

$$*11,42487 \times 10^{(-3)} \text{ MN} = 9,109 \times 10^{(-3)} \text{ [MN]}$$

$$\sigma_{m,t2} = \frac{9,109 \times 10^{-3} \text{ MN}}{0,081 \text{ m}^2} = 0.11246 \text{ [MPa]}$$

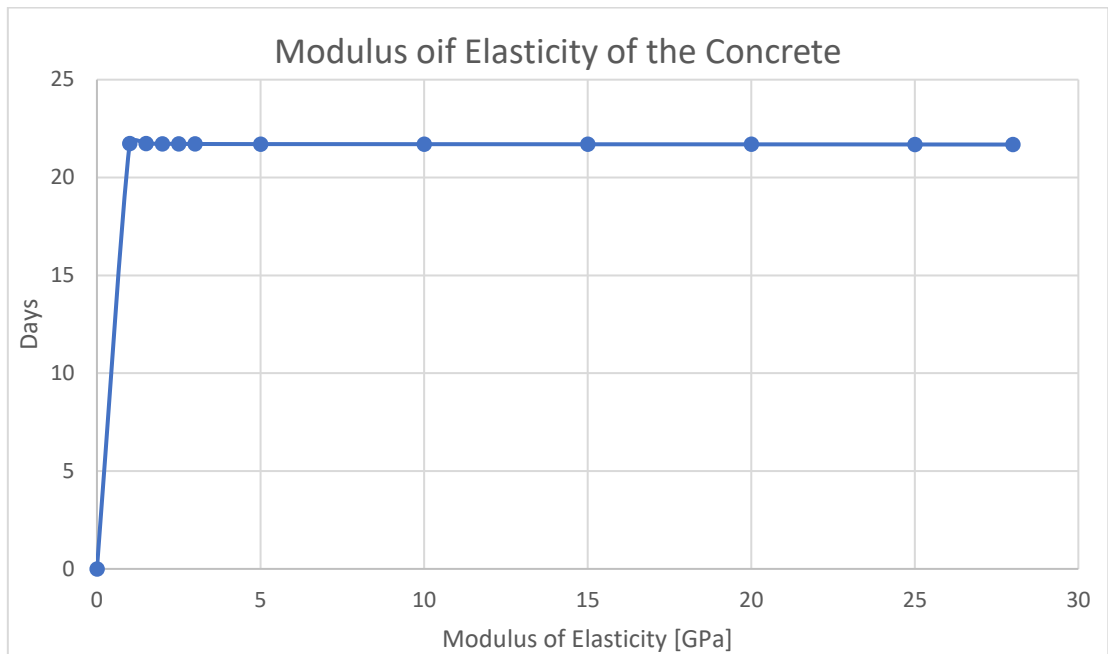
$$\phi_{m,t2} = 2,852273 \text{ [-]}$$

$$E_{m,t2} = \frac{E_{m,t0}}{1 + \phi_{m,t2}} = \frac{6 \text{ GPa}}{1 + 2,852273} = 1,557522 \text{ [GPa]}$$

Further calculation will be provided in table and placed here in the final form.

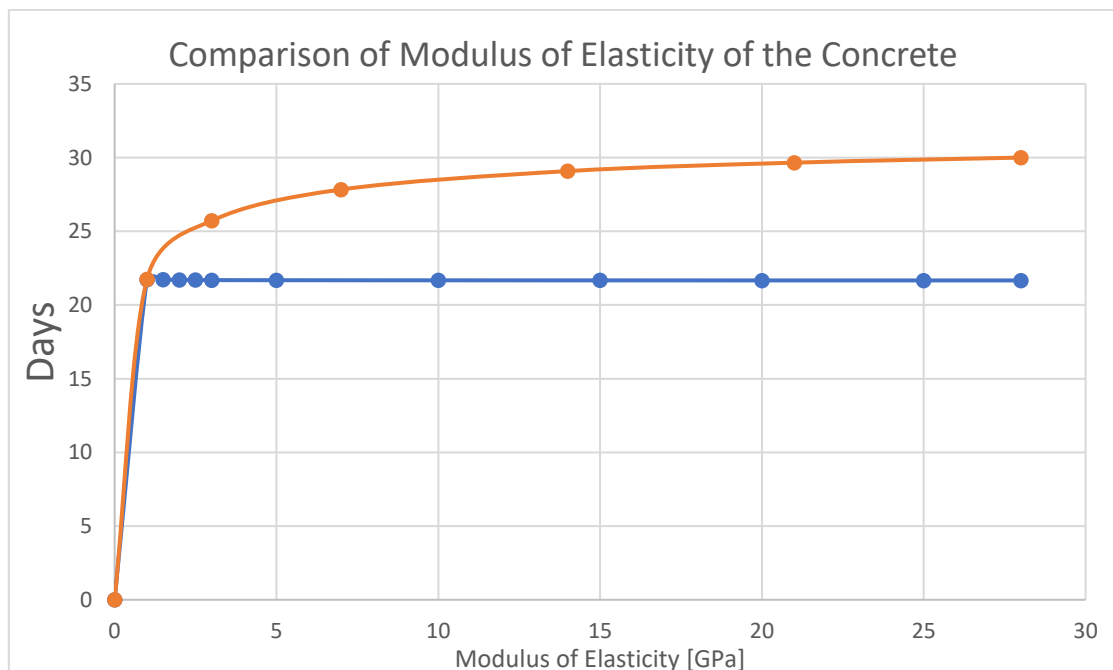
t [days]	Ec,t1	Em,t1
1	21.72771	1.554422
1.5	21.71691	1.557522
2	21.70675	1.560628
2.5	21.69702	1.563741
3	21.68765	1.563746
5	21.67936	1.56375
10	21.67313	1.563754
15	21.66863	1.563758
20	21.66595	1.563762
25	21.66495	1.563766
28	21.66495	1.56377

Modulus of elasticity of Concrete (See chart 55). Time to Modulus of Elasticity dependence.



(Chart 55. Modulus [GPa] to time [days])

Comparison of Theoretical and Calculated Modulus of Elasticity of the Concrete after during first 28 days after casting (Chart 56).



(Chart 56. Comparison Theoretical and Calculated Modulus of Elasticity)

4. Conclusion

From the results we may conclude, that in all the cases, which were described in this work have positive influence to the pouring the fresh Concrete inside the channel of Reinforced Concrete Masonry, especially the overall Load-bearing capacity plus the Moment resistance is increased. The Concrete creates the additional compressive material, which bears the loading and unload some portion from Masonry structure.

In the view of stability of ventilation tube the pouring of the Fresh Concrete inside the Chimney channel the described technic increases the Axial Load-bearing of the tube by 300%. as the result we may say that the supports should placed at least 1 m from each other if the duct is Aluminium .

What concerns the Creep, in our given Support for Lintel the Concrete takes approximately 30% of the Reaction Force and has the Creep slightly bigger, than the Masonry, because our Concrete mixture was not cured at all and just left for 24 hours for hardening to get the strength. In ideal case, the Fresh Concrete should be left for hardening more, than 24 hours to get more strength and reduce the Creep.

To summ everything up, the strengthening of Masonry Chimney is essential and it can be used not only in old Masonry structures, but also in Concrete buildings. This technique especially will be suitable for Russia, where in USSR a lot of building were constructed with Masonry and these facilities had common heating system in their Ground Floor. Usually more than 1 Boiler was located, as afterwards they had more than 1 Chimney. The trend to do reconstructions and make new doorway openings next to the Chimney is common these days.

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