Innovative design for repair of corrected industrial reinforced concrete structures of light soda silos - Solvay Sodi AD, Devnya

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Abstract: *The report discusses the main parameters of a developed design and technological project for the implementation of specific repair and restoration works of built in the mid-1970's corroded concrete reinforced structures of LIGHT-SODA SILOS – SOLVAY SODI JSC. The purpose of the design is to comply with the requirements for reasonable sufficiency of the additional new steel-reinforced concrete coating (jacked) to realize a lightweight variant of the protective layer against corrosive production factors, atmospheric influences and other specific chemical impacts. The project envisages a technological variant for the implementation of an additional healing thin repair reinforced concrete layer (overlay), based on the specific characteristics of high-tech hybrid fiber-reinforced "wet" sprayed concrete with the participation of specially selected high-range water-reducing and internal-crystallization chemical admixtures. The report provides information on the basic physical-mechanical and technological characteristics of the "wet"-sprayed concrete, as well as the main stages of structural design with specific structural details. According to the static scheme of the facility, it is proposed to specify the allowable load-state of the structure during the repair works.*

Keywords*: CORRODED CONSTRUCTIONS, CONSTRUCTION AND TECHNOLOGICAL DESIGN FOR REPAIR WORKS, HIGH-TECH HYBRID FIBER-REINFORCED "WET"-SPRAYED CONCRETE, HIGH-RANGE WATER-REDUCING AND INTERNAL-CRYSTALLIZATION CHEMICAL ADMIXTURES*

1. Introduction

The steel reinforced concrete structures of LIGHT SODA SILOS "4" & "5" - SOLVAY SODI AD, DEVNYA, were built in 1973 and they still operate under the combined impact of exploitation and environmental factors, some of which display significant corrosive potential. The latter violated the quality of the steel reinforced concrete, and serious corrosive damages were located within specific areas - **Photos 1 and 2**.

Photo 1 *LIGHT SODA SILOS "4" & "5" general view*

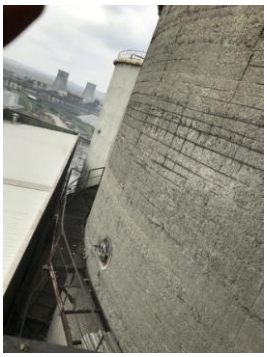


Photo 2 *LIGHT SODA SILOS "4" & "5" typical concrete damages*

The preliminary analysis of possible technical solutions produces a limited number of reasonable options basically due to the specific character of the operational units. Moreover, their operation cannot be entirely excluded from plant's overall operational regime during a reasonable period of time. One should also note the absolute unsoundness of the "by the job" approach to repair, i.e. repair of local areas where the damaged state of the structure has been visually established. This is so since such an approach would indefinitely prolong repair whereas the escalation of corrosion damage would proceed in neighboring areas.

The design and execution of necessary repair/recovery operations based on subsequent technological regulations, concerning the employment of a standard repair systems pursuant to a series of standards **BDS EN 1504: 1-10 Products and systems for the protection and repair of concrete structures,** is also rejected a priori. Otherwise, this would yield the use of standard compatible mixes with different function, deposition of layers with comparatively large thickness and inevitable rise of repair cost.

The conventional construction of an entirely new steel reinforced concrete casing (a monolithic method) yielding increase of the wall cross section by at least 10 cm, is also unacceptable. Otherwise, the surface of the outer walls would be simultaneously and entirely uncovered resulting in total exclusion of the reinforcement from operation and hazards to the structure safety. Besides, such an approach imposes inadmissible complex requirements to the repair/recovery concrete and rise of cost.

Shotcreting of a new special concrete layer ("jacket"), without the use of formworks, employed to recover the initial cross section, seems to be the most appropriate technological method. Such an approach is adopted as a basic one in the present technical project, where as a technical-economical comparison between the two methods of shotcreting - "dry" and "wet" concrete covering, shows imperative advantages of the "wet" one [1,2]. The design envisages a technological variant for the implementation of high-tech hybrid fiber-reinforced "wet" sprayed concrete with the participation of specially selected high-range water-reducing and internal-crystallization chemical admixtures.

The purpose of the design is to observe the reasonable sufficiency requirements of the new concrete cover above the existing steel reinforcement, and to execute a thin protective overlay with special technical characteristics against the industrial factors influencing corrosion, weather impact, freezing, carbonization, UV rays, etc.

A basic requirement to the project is the observation of the principles of reasonable sufficiency of the offered solutions, concerning optimization of the thickness of the new concrete cover of the reinforcement, deposition of a low-weight anti-corrosion layer, protecting from atmospheric impacts, freezing, carbonation, UV rays etc. In addition, development of technical regulations of the planned repair is also envisaged.

2. Loads and actions on the silos

Considering the nature of the designed repair and renovation works, the structural stability and capacity has been checked in construction stage, taking into account the state of the silo during the repair works. In such a design situation, the silo is partially filled with light soda ash and parts of the body, ring beam or columns are partially weakened. For this purpose, the applied loads have been defined in compliance with **BDS EN 1991-1-6: General actions during execution.** Considering the estimated duration of the repair works per one spraying stage (each one over 3 days) and according to **Table 3.1 of BDS EN 1991-1-6**, the atmospheric loads on the structure were defined with probability of occurrence once in 5 years.

The wind load is determined for terrain **category IV** and base speed with probability of exceeds once in 5 years - 26,5 m/s. The dead loads are defined on the basis of the material volume density and the geometry dimensions of the silo's elements. The load from the gallery above the silo is also reported.

Since a possibility is sought to avoid emptying the silo during the repair works, the calculation analysis has been performed for different degree of filling the silo with soda and respectively at different stages of repair works it can be filled differently. This filling capacity of the silo has been studied via data from the actual material circulation over the years. The records have been submitted by the Assignor and based on them the designer has made his estimation.

The Solvay's engineering team has specified the characteristics of the soda stored in the silo with the following parameters: volume weight: 0,50 t/m^3; angle of internal friction 40-45^0. This volume weight is confirmed by the fact that at the maximum volume of the silo of ~8300 m^3, the maximum filling capacity of silo "4" is 4130 t of soda.

3. Structural survey and status of the elements

The dimensions and location of the structural elements and reinforcement have been defined on the basis of the archive drawings.

Visit and visual inspection of the reinforced concrete structure has been performed to confirm or clarify the records data. The existing reinforcement steel was specified (A-III) as well as the concrete class (grade 300 ~, concrete compressive cube strength is 22,5 MPa). It should be noted that no essential damages have been observed in the reinforcement of the elements. Significant part of it is visible in the areas exposed to weather (the side of the columns, which is in contact with the outside air, the external cylindrical part of the silo body) but the visible reinforcement steel is in relatively good condition. The silo funnel (conical hopper), the supporting ring beam and the internal columns are predominantly in relatively good status and there is almost no visible reinforcement. Damage on the covering of the internal elements is observed only in the areas of leaks between the steel roof structure at level 15,00 and the silo.

4. Bearing capacity of the reinforced concrete structure elements during the repair activities and degree of silo's filling

A calculation check of the silo structure elements has been carried out, which indicates reducing of the element's sizes during the repair activities. For this purpose, the bearing capacity of the separate structural parts and sections of the silos was checked, based on their reduced sections at permissible level (as prescribed by design) of filling the silo for the respective pouring stage.

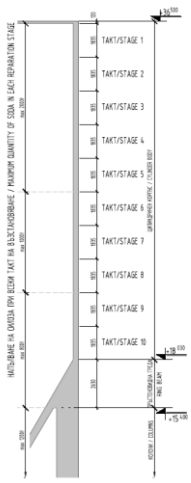


***Fig. 1** Maximum permissible soda content during the repair and renovation works*

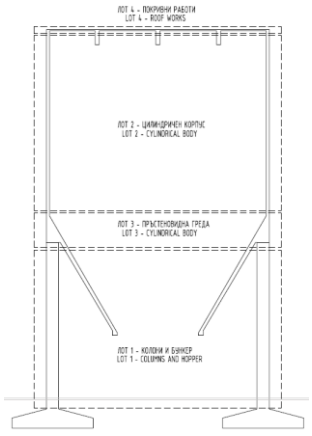


***Fig. 2** Sequence of the repairing works*

4.1. Different sections of the cylindrical body of the silo

The possibility to reduce the shell structure section after the sandblasting of its surface has been considered, which will cause partial exposure of the external reinforcement. The following has been found:

- In the area of close to the transition between the cone and the cylinder, the section is overexposed to bending moments (also known as edge bending moment area). Critical is the bending capacity in this area, whereas during the repair works the bending capacity checks are fulfilled if the silo contains up to 800 t of soda. The last impose that the silo cannot be filled with more than 800 t of soda at the time pouring stage 9-th and 10-th are ongoing as per **Figure 1**.

- In the area outside the edge bending moment areas, the bending moments have extremely reduced values. Critical shall be the tensile strength of the ring, where part of the reinforcement is exposed and separated from the concrete due to sandblasting. At different operational areas of the silo the degree of possible filling is different and is shown on **Figure 1.**

4.2. Ring beam

The main internal forces within the ring beam are the axial forces and bending moments. Having considered the possibility to reduce the bearing capacity of the element following its sand-blasting or hammering, the permissible content of soda is found to be 800 t. This parameter shall be controlled during the repair works on the beam.

4.3. Columns

The silo columns are under bending and compression. A calculation check of the capacity of the columns was done.

The damages on the columns are mostly on their external side which is exposed to weather. In this area sandblasting is planned to be performed, installation of reinforcement mesh and applying the wet mix shotcrete process for spraying of concrete coarse aggregate containing **Mix №1** [1]. Prior to the eventual removal of carbonated concrete, it is foreseen that the vertical rods will be braced by stirrups against buckling in view of the compression stresses existent in them. Work on "external" columns can be done with the presence of soda up to 1200 t.

The internal columns, subject to their good status, will undergo only sandblasting of their surfaces and wet mix shotcrete process for spraying of a special passivating restorative without concrete coarse aggregate containing **Mix №2** [1]. They may be processed simultaneously. The degree of permissible filling of the silo during works on all elements is shown on **Figure 1.**

5. Description of the renovation and strengthening measures

Further to the survey and structural analysis made, the following strategy for strengthening and renovation has been adopted. In view of the necessity to reduce the quantity of soda contained in the silo during the repairs, the works on each of the silos shall be done separately. Having analyzed the data provided by the Client about the degree of filling the soda ash light silo per month for the year 2017 till issuing the design, it was found that if the silo operate separately, the total quantity of soda produced could be stored at the reduced capacity of the silo undergoing repairs as per the requirements of the present design.

The sequence of renovation follows like this – **Figure 2:**

- Lot 1 – columns and hopper;
- Lot 2 – cylindrical body;
- Lot 3 – ring beam.

5.1. Columns

The columns are classified as two types - **Type 1** and **Type 2** according to **Figure 3.** The **Type 2** columns are not in direct contact to the outside environment and visually look in very good condition. Damages are observed on the columns which are in

contact with the outside weather conditions (**Type 1**). These areas include the possibility of carbonated concrete being removed, the reinforcement of the longitudinal and transverse reinforcement, and installation of a technological reinforcement mesh and the spraying of the **Mix №1**.

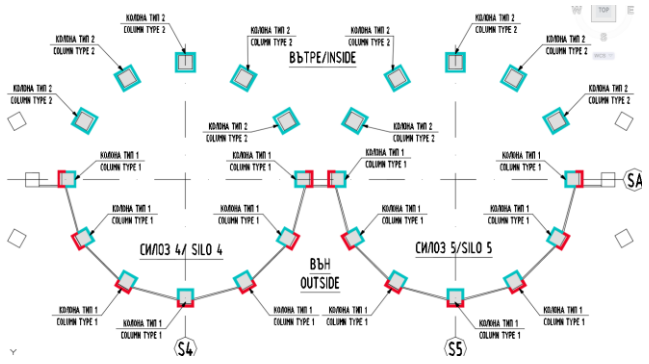


***Fig. 3** Columns classifications*

For the internal columns (**Type 2**), only wet mix shotcrete spraying of special repair, restorative and passivating **Mix №2** as per specifically developed recipe is planned.

The repairing works on each column are to be executed independently for the upper and the lower half.

Sequence of working on the one half (upper or lower) of the column:

- the soda content shall be compliant to the values on F**igure 1** (1200 t);
- The concrete cover in the repaired zone is removed in order the top surface of the existing bars to be visible (**Figure 4)**. **If healthy non-carbonated concrete is reached before uncovering the bar's surface, no more concrete to be removed**;
- Execution of vertical bars fixing by bonding bars C1 and bars are fixed by welding (**Figure 5)**;
- Checking the stage of carbonization in areas with removed concrete cover;
- The areas with stated carbonization are to be marked and the concrete around each bar is to be removed until healthy concrete is reached, but not to be reached deeper than 80 mm from the original dimensions of the section (**Figure 6**). **If in some zone healthy concrete is reached, before uncovering some reinforcement bar, that concrete should not be removed and the bar remains uncovered**;
- The existing reinforcement is being repaired by welding if necessary;
- Welded meshes are applied by anchoring hooks;
- Shotcreting by **Mix №1**, and forming the surface by side formwork;
- After removing of the side formwork transition should be sprayed with **Mix №2 (Figure 7).**

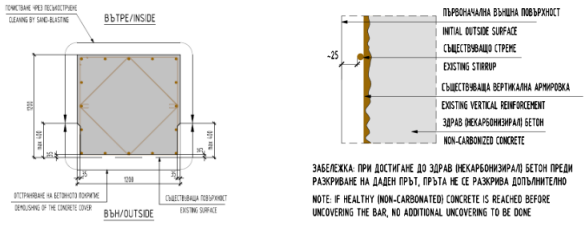


***Fig. 4** First stage of the preparation – concrete cover removal for columns Type 1*

5.2. For the cylindrical part of the silo above level +18,03

For this part of the silo repair works from top to down are planned in spraying stages with height ~1,8 m along the perimeter of the cylindrical part. After making the soda content compatible to the values shown on **Figure 1**, the processed area shall be sandblasted in order bars' surface to be uncovered (**Figure 8**) **while not penetrating further below the reinforcement unless happens during the blasting** due to local damages in the reinforced concrete section. The carbonation degree is being checked and the carbonated areas should be marked. The carbonated concrete around each bar is to be removed but it should not be reached more than 20 mm behind the vertical reinforcement. If noncarbonated concrete is reached before uncovering the bars, no additional uncovering to be done (**Figure 9**).

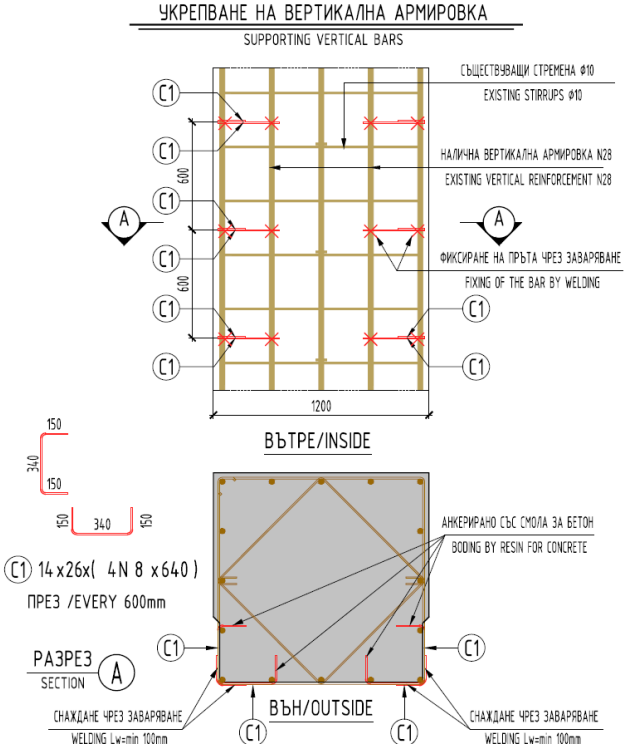


***Fig. 5** Existing bars fixing*

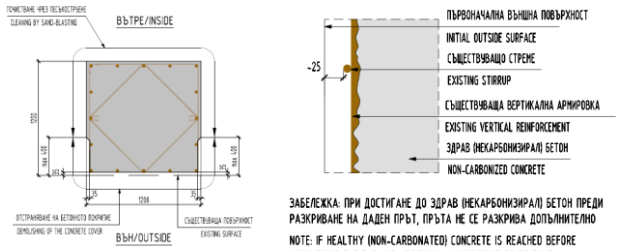


***Fig. 6** Second stage of preparing – removal of carbonated concrete*

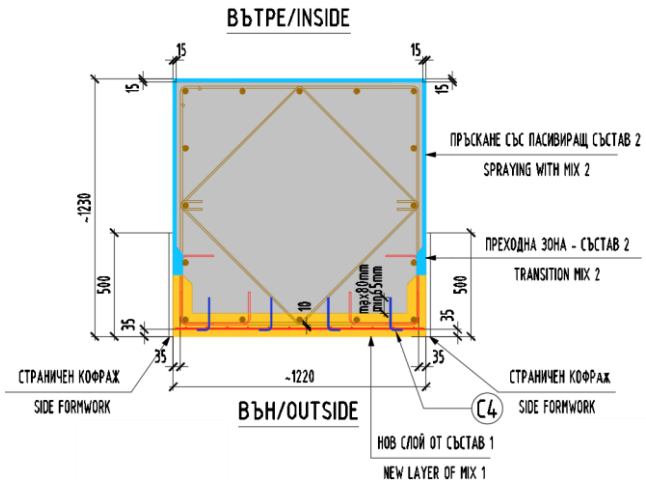


***Fig. 7** Repaired section*

Upon finding of interrupted reinforcement bars or damaged overlapping joints, then they shall be joined by welding details.

Over the cleaned surfaces, welded reinforcement meshes N6/ (150x150 mm) are installed. They are installed via anchoring of the reinforcement bars in the concrete at a distance of up to 300 mm at both sides (anchoring depth 80 mm - **Figure 10**). Point fixators (rebar spacers) shall be additionally installed, too. They serve as reference points when forming the cylinder curve after applying the shotcrete.

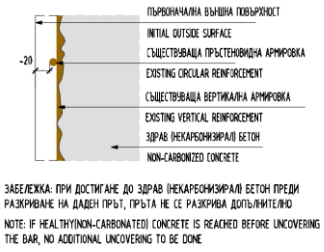


Fig. 8 *First phase of carbonated concrete removing in the cylindrical body*

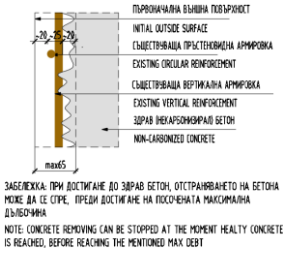


Fig. 9 *Second phase of carbonated concrete removing in the cylindrical body*

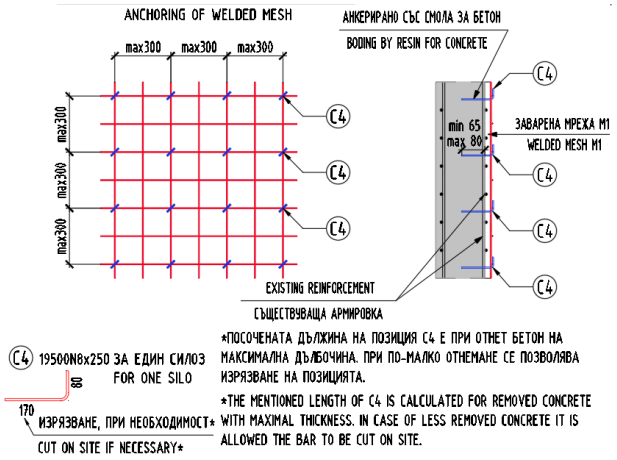


Fig. 10 *Anchoring rods for reinforcing mesh*

Once the blasting and reinforcement works are finished, follows the wet mix shotcrete process of spraying **Mix №1** as per specifically developed recipe. Two days afterwards the next spraying stage shall be prepared. There is an exception only when moving from spraying stage 10 to the ring beam. Then this period is four days afterwards.

5.3. For the ring (support beam)

The impairments of the ring beam include damages on its concrete cover in the areas exposed to weather and leaks. Installation of reinforcement is planned to be executed and shotcreting of **Mix №1.**

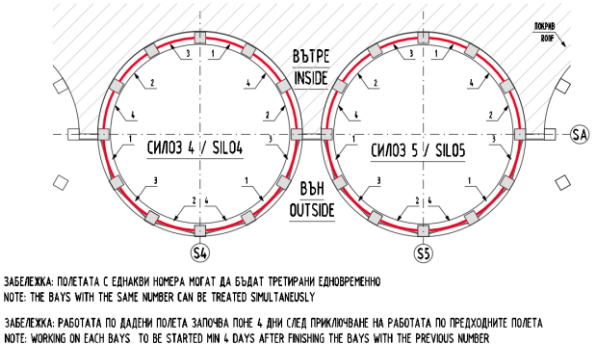
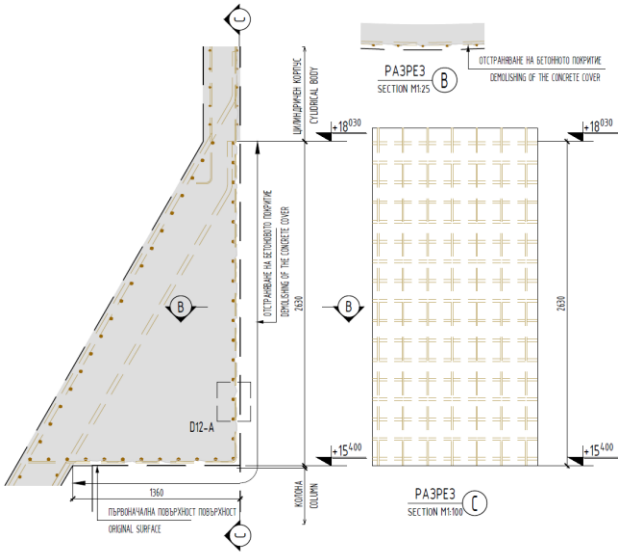


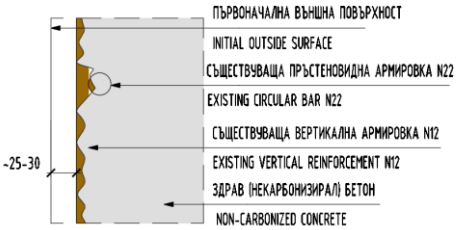
Fig. 11 *Scheme of sequence of the reparation works*

***No more than three bays are allowed to be treated at the same time/ the ones with same number acc. figure 20, and next group of bays can be started at least four days after finishing the previous ones/.

- The permissible soda content in the silo during the repair works on the ring beam is shown on **Figure 1** – 800 t;
- The concrete cover of the bay is removed in order the top surface of the existing bars to be uncovered;
- The degree of carbonation is checked;
- If reached concrete is not carbonated, welded meshes to be installed by anchoring bars C5. **Mix №1** to be applied;
- If there are areas with carbonized concrete, they must be marked. The next repairing works must be executed in zones including maximum the number of bars quoted. If healthy concrete is reached before uncovering an entire cross-section of the bar in the working zone, no more concrete to be removed. Every next zone to be started after the reinforcement installing, shotcreting and strengthening the previous zone are finished (**Figures 12-14**).



ЗАБЕЛЕЖКА: ПРИ ДОСТИГАНЕ НА ЗДРАВ БЕТОН ПРЕДИ ПОКАЗВАНЕ НА АРМИРОВКАТА, ТО ОТСТРАНЯВАНЕТО НА БЕТОН СПИРА;
NOTE; IF HEALTY CONCRETE IS REACHED BEFORE UNCOVERING THE REINFORCEMENT, CONCRETE REMOVING TO BE STOPPED;



ЗАБЕЛЕЖКА: ПРИ ДОСТИГАНЕ ДО ЗДРАВ (НЕКАРБОНИЗИРАЛ) БЕТОН ПРЕДИ РАЗКРИВАНЕ НА ДАДЕН ПРЪТ, ПРЪТА НЕ СЕ РАЗКРИВА ДОПЪЛНИТЕЛНО
NOTE: IF HEALTY / NON-CARBONATED CONCRETE IS REACHED BEFORE UNCOVERING THE BAR, NO ADDITIONAL UNCOVERING TO BE DONE

Fig. 12 *Uncovering top surface of the existing bars in the treated bay*

In the areas of the additionally built roof structure, works on the ring beam shall be carried out without dismantling the roof structure. The areas above the roof shall be treated first and the roof sheet can be cut so that the reinforcement mesh can pass underneath. When the area above the roof is finished, the one below the roof is processed. Steel structures or concrete elements shall not be dismantled. No more than 25 mm (measured from the original sizes of the section) concrete to be removed in the area of the embedded items.

5.4. Cone funnel (hopper)

In view of the good status of the conical part of the silo (the hopper), surface processing is planned including the following activities:

- sandblasting;

- dust-removal treatment;
- polymeric composition primer;
- thin passivating polymer covering applied by roller.

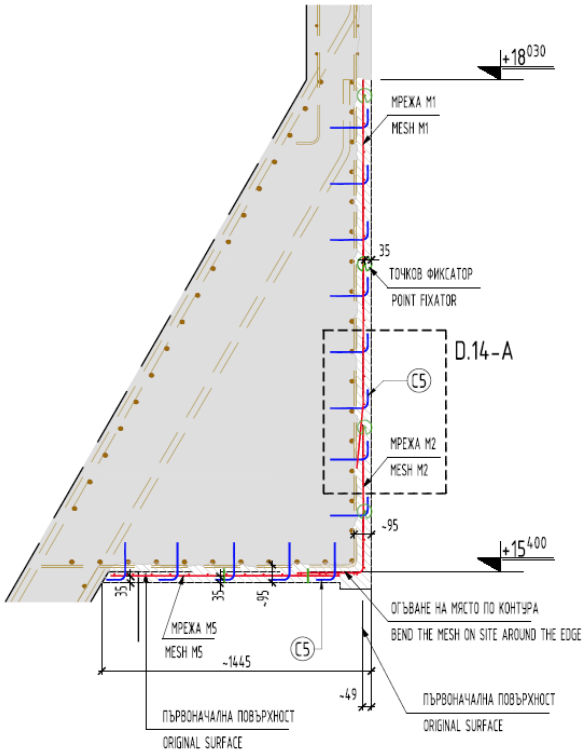


Fig. 13 *Repairing works of the bays if non-carbonized concrete is reached in uncovering the top surface of the bars*

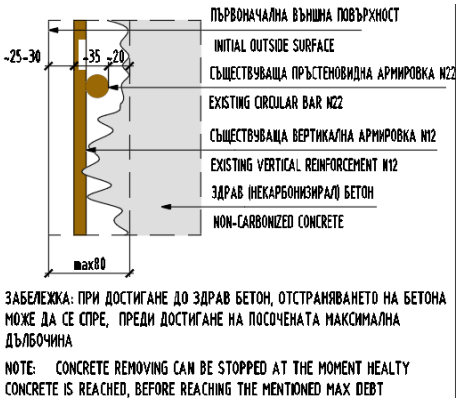


Fig. 14 *Additional uncovering the bars if concrete is carbonated*

6. Conclusions

The specific innovative design of repairing works needed is presented. Based on wet-shortcreting works the proposal contains all necessities stages – static calculations, specific detailing, technological approaches and working stages.

Using new developed wet shotcrete mixes with hybrid reinforcement (steel mesh and micro-polypropylene fibres) and new range of internal crystallization admixture gives attractive prospects for optimal repairing works to be executed. Nowadays the design developed is in progress.

Acknowledgments

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7. References

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