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## PECULIARITIES OF THE CORROSIVE STATE OF THE IRON COLUMN IRON PILLAR IN DELHI, INDIA

***Abstract:*** *The paper considers the iron column Iron pillar located in the archaeological complex Qutub in Delhi city (India), which has not corroded for 16 centuries. The mechanism of atmospheric corrosion in this column has been reviewed. The hypothesis about the nonappearance of corrosion processes on the surface of the column for a long period of time has been suggested.*

***Key words:*** *corrosion, iron column Iron pillar, water film, molecules of water vapour, dissociation, ferromagnetic domains, Lorentz force.*

**УДК 620.193**

## ОСОБЕННОСТИ КОРРОЗИОННОГО СОСТОЯНИЯ ДЕЛИЙСКОЙ ЖЕЛЕЗНОЙ КОЛОННЫ IRON PILLAR

***Аннотация**: В статье рассматривается железная колонна Iron pillar, расположенная в археологическом комплексе Кутуб в г. Дели (Индия), которая в течение 16 столетий не подвергается коррозии. Рассмотрен механизм развития атмосферной коррозии в данной колонне. Предложена гипотеза о невозникновении процессов коррозии на поверхности колонны в течение длительного периода времени.*

***Ключевые слова:*** *коррозия, железная колонна Iron pillar, пленка влаги, молекулы водяного пара, диссоциация, ферромагнитные домены, сила Лоренца.*

The ways of corrosion resistance (durability) of metal constructions has been an actual issue throughout the world. Despite the achievements against metal corrosion the problems are intensifying due to continuous growth of metal foundation and strong requirements for metal exploitation conditions. Direct loss due to corrosion (reproduction and replacement of the equipment out of use) has approximately reached 5.5 billion dollars in the USA in 1955, 250 billion francs in France in 1959, not less than 5-6 billion rubles a year at the end of 1960s in the USSR [1]. Later, according to the evaluation of the National Standards Bureau, presented to the USA Congress in 1978, the total annual corrosion loss has amounted to 70 billion dollars in the USA [2]. The comparatively recent research of the American Federal Administration of Automobile Roads “Corrosion loss and preventive strategy in the United States”, which summarized the results of two-year studies held from 1999 to 2001, estimated total annual direct corrosion losses to 276 billion dollars, i.e. approximately 3% of the gross national product of the USA [3]. In total, metal corrosion losses and expenses on protection in industrially developed countries amount to 4% or more of the national profit. Mostly, the losses due to metal corrosion are connected with the atmospheric corrosion. This is the most widespread corrosion type, it appears so often and in various ways that preventive measures against this type hasn't lost its actuality.

In this regard, the iron column Iron pillar (Fig. 1) in the archeological complex Qutub in Delhi city (India) is of great interest, which hasn't corroded for more than 16 centuries. Many scientists all over the world have studied this column, but haven't guessed the riddle – why hasn't this column corroded for so long? We have also visually studied this column, and made a conclusion on the corrosion mechanism of this construction. First, we will give some information about the history of the column Iron pillar, and other related studies.

**Fig.1 - The iron column Iron pillar in Delhi city**

The column was set in the 5th century at about 20 km away from the modern Delhi. It resembles a truncated cone. The column weighs about 6 tons [4].

A common opinion about the way the column was built hasn't been given so far. The iron for the column was taken from the iron ore by means of direct reconstruction using the charcoal. Due to the charcoal there is little sulfur in the metal. The iron jaw, which is taken during the ore reconstruction, has to be rolled to squeeze the slag. However, the slag can't be removed in total, that's why there are so many non-metal inclusions in the metal. Metal clods weighing 20-30 kg are weld by hammering: there are hammering signs and welding lines on the column [5].

Some authors declare that the column was casted. The first contribution was made by Alexander Cunningham [6]. He stated that the column height is not less than 60 feet (18 m), and the weight is 17 tons. In his opinion, the column was all-of-a-piece.

Other scientists consider that the column was built by welding the separate blooms weighing 36 kg, which were further hammered. The author [7] thinks that the ancient metallurgists ground the jaw of wrought iron into powder, and sifted the powder to get pure iron. After that, the pure iron powder was heat to redness, so the particles stuck together by hammering. Probably these iron pieces were used to build a huge column in Delhi.

By the end of the 19th century at least one article saying that the column was welded had been published [8]. In 1912 the famous metallurgist Robert Hadfield in his work [9] convincingly stated that the column iron was not pure, and also gave the results of the first chemical analysis on the column metal. According to his data, the metal in the composition resembles the modern steel 08. Indeed, Hadfield continued stating that the column was all-of-a-piece, referring to Cunningham. However, Hadfield was fairly corrected in reviews of his paper [10].

Some researchers state that some time ago the atmosphere of Delhi contained increased amount of ammonia (due to a big number of people and animals) which allowed getting a protective layer of iron nitrides on the surface of the column in subtropical climate of India. In other words, the column was as if nitrided by the nature itself [11].

Tourist guides in Delhi city often say that noncorrosive steel was used to build this monument. However, the analysis held by the Indian scientist Chedari shows, that the Delhi column does not contain doping elements that increases corrosion resistance (Table 1) [12].

**Table 1**

**Chemical composition of the column material, %**

| Carbon | Silicon | Sulfur | Phosphorus | Nitrogen | Iron |
|---|---|---|---|---|---|
| 0,08 | 0,046 | 0,006 | 0,114 | 0,032 | 99,722 |

There is an opinion that the material of the column is of low-carbon steel clean of sulfur and contaminated with phosphorus. According to the studies [13], the average chemical composition of the column (in %) is as follows: carbon – 0.15, phosphorus – 0.25, sulfur – 0.005, nitrogen – 0.02, silicon – 0.05, manganese – 0.05, copper – 0.03, nickel – 0.05, and the remaining is iron. The amount of copper, manganese, silicon and nickel is connected with the specificity of the Indian iron ore, but it is within the standard limits.

Some hypotheses suggest that ancient metallurgists consciously or unconsciously created a special protective layer. In particular, it is considered that the column was treated with superheated steam, so the steel blueing took place [11].

One more hypothesis about the column appearance is connected with the iron meteor that fell on the Earth. Scientists say that there is a significant amount of anomaly of the iron of meteor origin at the bottom of the sea several tens of kilometers away from Mumbai. It is considered that 15,000 years ago a huge meteor fell on this territory, which had been a dry land before. Those times people considered meteors sacred, and decided to make columns from it in honor of their gods [14].

As the column has long been the object of cultural reverence, and then, a specific sight, it has never lacked human attention. The devotions required lubricating the column with oil and incenses. Due to that the column has always been covered with a layer that prevented it from corrosion [11].

There is a version, that during smelting the metal “by eye”, which happened in ancient times, there is a possibility of huge deflections in the metal quality. The column may be one of these exceptions [7].

There is also a theory, that the iron column in Delhi city is protected with a slag layer, formed during its preparation. Stone moulds for casting has been found several kilometers away from the column. A distinctive feature of this mountainous region is a high level of radiation. It is probable that after casting, the column laid for several years, and due to radiation the upper layer turned into amorphous iron, which is corrosion-resistant. The chemical composition with high level of phosphorus, and the amorphous structure of the upper layer iron create corrosion-resistant cover [11].

One can not see the familiar traces of rust on the surface of the column. The first one and a half meter of the column has been polished with the hands of numerous pilgrims. Further the column is black, and the top of the column is bluish or even brown due to the oxide layer. Several hypotheses explain that the corrosion-resistance of the overground part of the column is due to the dry ambient air in Delhi [11]. The Swedish metallographer Y. Wranglen conducted experiments, in which cut pieces of the column were taken to the seashore and the industrial district of Sweden (marine and industrial media are the most dangerous for steel), where the pieces completely corroded. The underground part of the column, which has also been studied by Y. Wranglen, is covered with 1 cm thick rust. There are also 10 cm thick corrosion pits.

In 1953 Hudson published a message about the speed of corrosion of copper steel and zinc in areas, including the column area, with different climatic conditions [15]. The atmosphere of Delhi city was last but one in the list of aggressive climatic conditions, letting only Khartoum city be the driest. Even during monsoons the humidity of Delhi air exceeded the critical value (70%), in which steel significantly corrodes, only in the morning. In Delhi atmosphere even loose zinc is oxidized insignificantly.

The Russian scholars have discovered several never-before-seen peculiarities of the column [16]. Thus, the foundation forms a vertical energyfield flow (invisible to the eye), whose shape resembles a candle light 8 m in height and more than 2 m in diameter, wrapping the column around. The studies held show that there is an additional source of energyfield radiation at the height of 3 m within the column, which was formed in the form of a small pressed rectangular packet made from thin sheets of stable radioactive metal (like astatine and polonium). The source of radiation was put into the column through a drilled and later damped hole. The Russian scholars suggest that the energyfield cover of the iron column is a reliable protection from corrosion. It is admitted that the reason for the rust on the column in the area of luting to the foundation is a water film from rain and dew, which flock on the horizontal surface of the foundation that lies beyond the energetic cover. Iron oxidizes through this film, and this is a vulnerable spot of the column.

The Indian scholars from the Kanpur Technological Institute state [17, 18, 19] that the column contains a lot of phosphorus, which has created a kind of rust preventative layer, having reacted with iron, water, and oxygen. The scientists consider that the ancient blacksmiths were not aware of unique chemistry of alloys, and selected iron composition based on the experience.

There are some explanations that the column conserves heat for a long time due to its mass, and dew does not form on its surface due to local climatic conditions [11].

In accordance with the above mentioned we can make a conclusion, that resistance to corrosion of the column in Delhi is due to the following factors: purity of the iron, high concentration of phosphorus, low concentration of sulfur, absence of other metal additives formed on the surface of the ash cover, high-quality welding, dry and clean atmospheric condition, and heat effect of the whole column mass. Our opinion leans towards the latter, and we shall offer the following mechanism of corrosion formation on this column.

On the part of a mechanism, the atmospheric corrosion is an electrochemical process. The main factor is relative humidity, which defines the intensity of the atmospheric corrosion wear. Atmosphere consists of mixture of gases called air, in which there are liquid and solid particles in a suspended state. The atmospheric air on the ground surface is usually wet. It means that it includes water vapour, i.e. water in a gas state, along with other gases.

The process of atmospheric corrosion takes place and propagates only in case on the surface of the metal there is a water film of certain thickness, which takes on the properties of an electrolyte (Fig. 2) [20]. The duration of the propagation of the corrosive process and the quality of metal, which has turned into corrosive products, depend on the length of the presence of the electrolyte film on the surface of the metal. The longer the film on the surface dries up, or the more often it renovates, the longer the corrosive process is, therefore, the more corroded the metal is. Despite this fact has been considered before, the mechanism of dissociation of water vapour, and its influence on corrosion have not been explained.

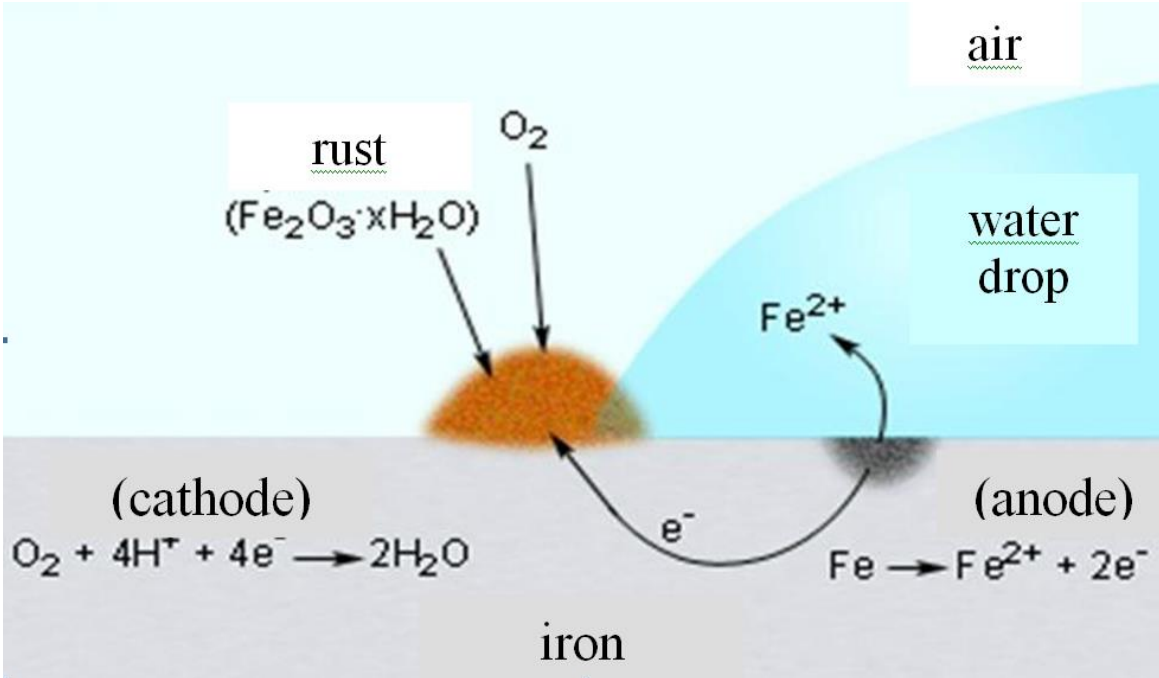


**Fig. 2 - The mechanism of electrochemical corrosion**

We suppose that while the molecule of the water vapour is moving up the place of evaporation, it is exposed to dissociation and is divided into ions $H^+$ and $OH^-$ (Fig. 3) due to friction and blow onto the atmospheric gas mixtures, in which the liquid and solid materials are in a suspended state. Further, most ions join the water film on the elements of steel constructions, which cover the disrupted areas of their domain pattern by means of the mechanism presented by us [21, 22].

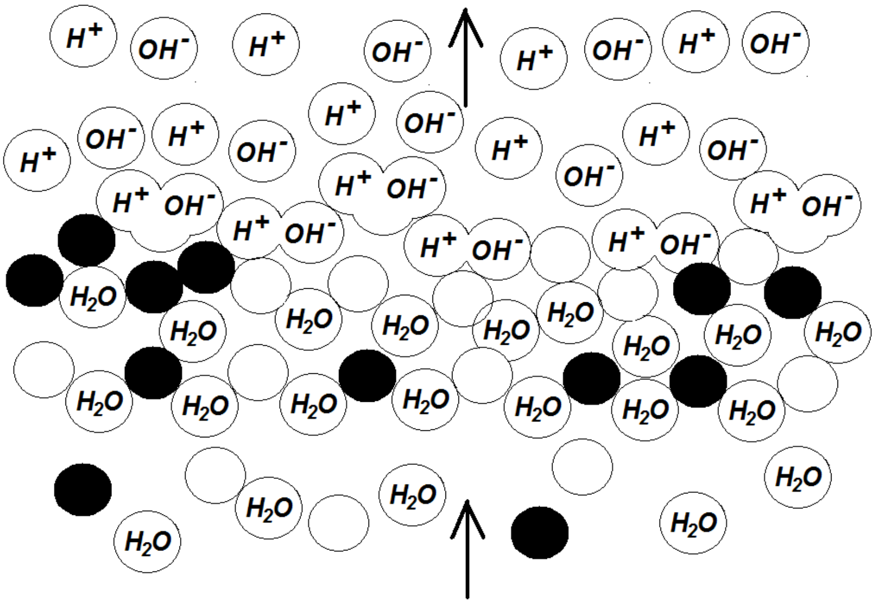


**Fig. 3 - Dissociation of the molecules of the water vapour due to friction and blow onto the atmospheric gas mixtures**

The ion $H^+$ «lost» by the molecule of the water vapour joins another molecule on the water film on the surface of the element of the steel construction, and forms the hydronium ion $H_3O^+$. The reaction of the dissociation of water film is as follows:

$$H_2O + H_2O \leftrightarrow H_3O^+ + OH^- \quad (1)$$

Due to the ability of the ion $H^+$ «to jump» from one molecule to another, the ions $H_3O^+$ and $OH^-$ are much more movable comparing to other monovalent ions. The anomalous movements of the ions $H_3O^+$ and $OH^-$ on the water film are also the consequence of hydrogen bonds between molecules. These bonds conduce the quick transfer of the ions $H^+$. For instance, one of the protons of the ion $H_3O^+$ can move along the hydrogen bond by jumping (Fig. 4) [23]:

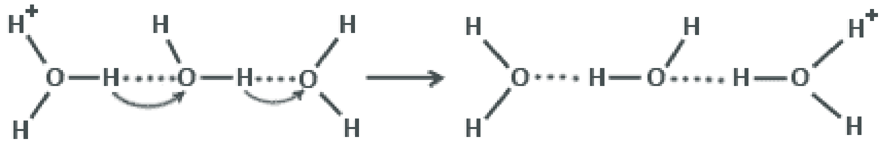

**Fig. 4 - The movement of the ion $H^+$ along the hydrogen bond by jumping**

The proton of the water molecule can move along the hydrogen bond in this way, interacting with the ion $OH^-$ (Fig. 5):

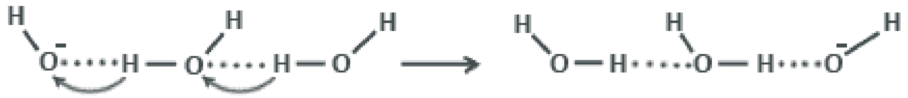

**Fig.5 - The movement of the proton of the water molecule along the hydrogen bond**

Both processes cause the migration of electric charge, and in case there is an applied field, they cause electric current. This, in its turn, propagates the electrochemical corrosion of the elements of the steel constructions by means of the mechanism presented by us [21, 22]. It means that the ions $H^+$ and $OH^-$ in the magnetic field created between the divided parts of ferromagnetic domains of the elements of the steel constructions will be exposed to Lorentz force. According to the direction of Lorentz force these ions will gravitate to the disrupted areas of the steel like gravitating to magnetic poles. As soon as the physical process ends, the chemical one starts. At the end of the reaction the ions $H^+$ recover and are absorbed by the disrupted area of the steel, and go to atmosphere in the gas form, and the ions $OH^-$ form iron hydroxide. Further, the film of iron hydroxide (II) $Fe(OH)_2$ and iron hydroxide (III) $Fe(OH)_3$ fill in the induced cracks of the disrupted areas of the steel, which results in the slowdown or termination of the process of atmospheric corrosion of the surfaces of the steel constructions.

On the part of the mechanism of corrosion propagation in the iron column in Delhi it directly depends on the heat exchange processes. The climate in Delhi is tropical monsoon. As everywhere in India, the extremely differentiated rainfall regime is typical to Delhi. The monsoon comes in June and continues until the late September, when wet air masses from the Indian Ocean come to the city. The summer in Delhi is hot and long, and the hottest months are May and June due to predominance of glowing air masses from deserts. The average temperature in June is +33,4°C, and the mean maximum is almost +40°C. The winter in Delhi is dry and cool for such low geographical latitude; however, due to flow of cold air from the Himalayas there is thick fog in winter in the city. Frosts are rare, but still there are some. The mean annual rainfall is 714 mm, most of which falls from June to August [24].

As it was mentioned above, the corrosion propagation on the surface of the column needs the water film. As it is already clear, the climate of Delhi is very dry. During the monsoons the air humidity in Delhi is about 70%, and the average temperature is about +30 °C. In such conditions even the water film formed on the column due to rain quickly evaporates.

During the day the column absorbs a lot of heat, and the water film cannot appear on its surface. At night there is a process of heat dissipation, and the temperature of the column is always higher than the temperature of the environment $t_{O.C.} < t_{Ж}$ [25]:

$$Q = cm(t_{E.} - t_{i.c.}), \tag{2}$$

where: $Q$ – heat; $c$ – heat capacity; $m$ –column mass; $t_{i.c.}$ – temperature of the iron column; $t_E$ – temperature of the environment.

In other words, water does not condense on the surface of the column, i.e. the mechanism of corrosion propagation set by us before does not start. The cracks on the surface of the column are not the sources of corrosion propagation. The ions $H^+$ and $OH^-$ does not disengage due to the absence of the water film on the surface of the column, and the existing electromagnetic fields between the cracks and Lorentz force in them cannot propagate the atmospheric corrosion. In our opinion, this is the very reason why the iron column Iron pillar located in the archaeological complex Qutub in Delhi city has not corroded for such a long period of time.

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