An Approach for Creating Certainty in Uncertain Environment: A Case Study for Rebuilding a Major Equipment Foundation

Abhijit Dasgupta and Suvendu Dey

Abstract The only thing that makes life possible is permanent, intolerable uncertainty; not knowing what comes next – Ursula Le Guin

To the common man, uncertainty is being in doubt or the state of being unsure about something. In scientific parlance, it is the unpredictable difference between the observed data and the model output. Sources of uncertainty may be many including material, manufacturing, environment, experiments, human factors, assumptions and lack of knowledge. Any one of these or a combination may lead to a significant loss of performance, that is, a large variation in output due to a small variation in the input parameters. The human being craves for certainty because the first priority for every individual on this planet is survival and the process of living contains many risks. This chapter deals with the various uncertainties that confronted a team of engineers during the course of rebuilding and upgrading an existing major equipment in an integrated steel plant. There were multiple challenges and uncertainties involved in every step of the rebuilding process.

Keywords Uncertainty • Equipment • Blasting • Shutdown • Rebuilding • Upgradation

1 Introduction

> The potentiality of perfection outweighs actual contradictions. Existence in itself is here to prove that it cannot be an evil – Rabindranath Tagore

The terms risk and uncertainty are intertwined and somewhat complex to analyse and differentiate. Risk can be defined as a state of uncertainty where some of the possibilities involve a loss, catastrophe or other undesirable outcome.

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Uncertainty, on the other hand, may be defined as the lack of complete certainty, that is, the existence of more than one possibility. The true outcome/state/result/value is not known. Human endeavour has always been to try and minimise risks even if it means working in uncertain conditions. Accordingly, 'one may have uncertainty without risk but not risk without uncertainty'. This chapter presents a case study where uncertainties and contradictions were overcome by the sheer will to achieve perfection and minimise potential risks.

In any integrated steel plant, one of the most important and major equipment is where iron ore, flux and fuel are burned in oxygen-enriched air to produce molten metal and slag. In a premier steel plant of India, such an equipment was first blown in the late 1950s. It was due for relining in the new millennium when the owners decided to upgrade it as well, from the existing 0.64–1.0 MTPA capacity. This was no mean task as every stage of engineering involved uncertainties and risks that had to be mitigated and solutions found.

In this chapter, an effort has been made to identify the uncertainties involved for this rebuilding and upgradation process. This chapter also describes how each uncertainty was analysed and dealt with in a rational manner to reach a level of relative certainty. Some explanatory sketches have also been included for a better understanding of the problem and the solutions.

2 Uncertainties

There were multiple challenges and uncertainties involved in every step of the rebuilding and upgradation process of the equipment. Some of the major uncertainties were:

- Knowledge of the existing foundation system
- Geotechnical data
- Load-carrying capacity
- Time constraint for shutdown of the equipment
- Developing model of foundation and subsequent blasting of part of foundation to simulate results
- Dismantling part of existing foundation by controlled blasting
- Restriction of energy propagation to the base raft of foundation
- Part load transfer through tower and part through existing foundation after partial rebuilding

Each of the above uncertainty has been elaborated in the following sections of this chapter, and steps to overcome them have also been described.

2.1 Existing Foundation System

Since the actual engineering of the equipment was done more than four decades ago, very limited and scanty data could be located from the client's archives. A few

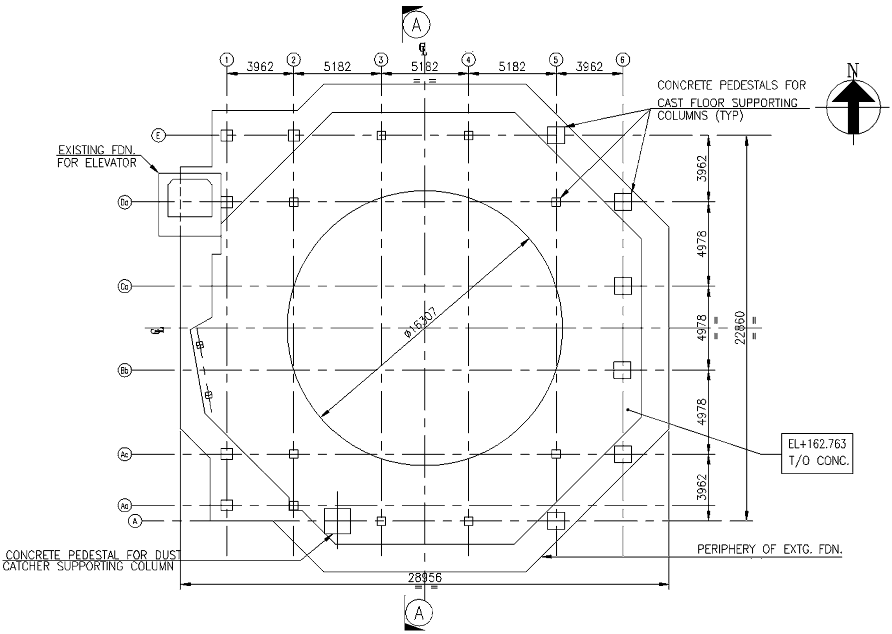


Fig. 1 Plan of existing equipment foundation

old drawings and an article, published in an in-house journal, were all that could be unearthed. Thus, credible information was limited and grossly insufficient. From the very limited data, it was understood that the main equipment shell was supported on a 52-ft.-diameter cylindrical concrete pedestal over a 13-ft.-thick octagonal concrete mat. The mat itself was supported on 28 nos. concrete columns, of size 5 sq. ft, founded on hard mica-schist rock. The column foundations were designed with safe bearing capacity of 4.0–9.0 t/sq. ft. Schematic sketches of the existing equipment foundation are shown in Figs. 1 and 2 below.

The above was the basis of a study undertaken by Dasturco to judge the feasibility of the proposed rebuilding and upgradation of the equipment.

2.2 Geotechnical Data

No soil investigation/geotechnical data could be found catering to the location of the existing equipment. From an old publication, as indicated earlier, it could be inferred that the foundation was designed with a safe bearing capacity between 4.0 and 9.0 t/sq. ft. Due to lack of data in the concerned area, it was decided to use existing geotechnical information from the neighbouring areas. Accordingly, from available soil investigation reports and test data of a nearby mill area, the gross safe bearing capacity of competent rock was estimated to be about 75.0 t/m^2. This corroborated well with the data obtained earlier from the technical article.

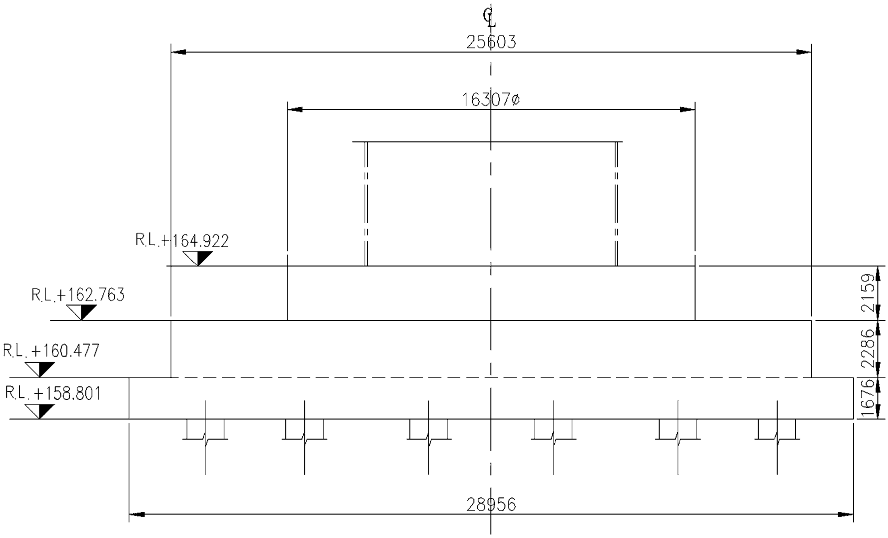


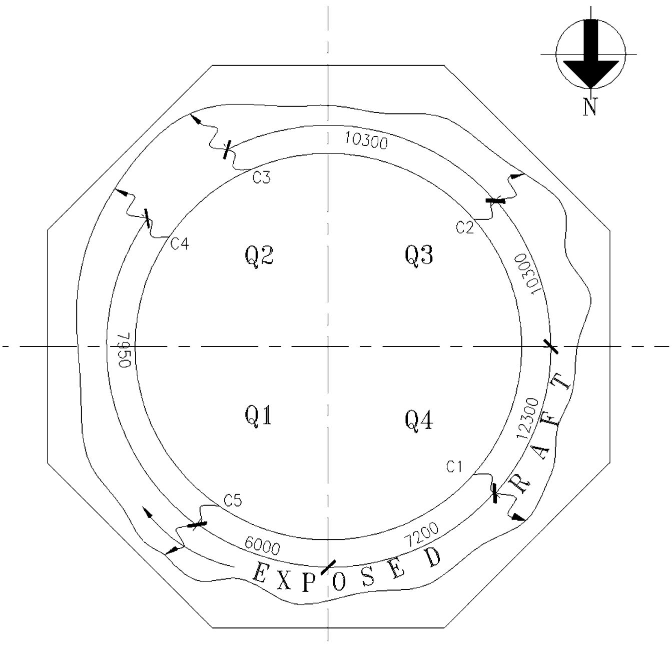
Fig. 2 Sectional view of existing equipment foundation

2.3 Load-Carrying Capacity

From the unearthed documents, no detailed load data on foundation could be found except an indicative vertical load of 21,000 Kips (9,258 tons) from the shell and cast house. However, there were necessarily other loads imposed on the foundation proper, and these had to be estimated to study the adequacy of the foundation system. A thorough reassessment of load was done considering additional loading from the elevator and one leg of dust catcher. Moreover, the equipment had undergone intermediate relining and modification works over the years. These would have increased the loading substantially. Considering all these factors, the vertical load on the existing foundation was reassessed and estimated to be of the order of 10,186 tons.

It was decided that the upgraded equipment would be free standing with four (4) tower legs around the shell proper. The design load from the shell and the tower legs considering all possible vertical loads for upgradation of the equipment for capacity enhancement were estimated to be to the tune of 13,000 tons. The existing foundation was not found to be adequate to carry the additional loads. Moreover, some cracks were noted on the foundation shaft and on top of the existing mat indicating signs of distress possibly due to flow of some molten iron on the foundation top. Based on the above, it was decided to get a thorough health study of the existing foundation done. Accordingly, the following studies were carried out:

- Cover metre test
- Carbonation test and pH
- Crack-width measurement and mapping
- Half-cell corrosion potential test
- Schmidt's rebound hammer test
- Ultrasonic pulse velocity test
- Core cutting and crushing tests



LEGEND
CRACK
CONTINUITY OF CRACK

CRACK NO.	CRACK LENGH (MM)	CRACK WIDTH (MM)
C1	780	1.2
C2	635	1.3
C3	3500	1.5
C4	665	0.9
C5	550	1.1

Fig. 3 Crack mapping on existing foundation

Results of the health study indicated that the concrete grade of the existing reinforced concrete foundation was between M15 and M20 (M15 grade shown in drawing/document). Mild steel reinforcement was provided and found to be in excellent condition with no signs of corrosion. Low degree of carbonation and residual alkalinity were also inferred from the tests. Moreover, vertical cracks on outer face of pedestal and horizontal cracks on top surface of mat could be observed. The crack widths were measured and mapped. This is presented in Fig. 3 below.

Thus, it was evident that the structure was under distress for quite some time. Accordingly, Dasturco made the following major recommendations in the feasibility report:

- The proposed four (4) towers, around the shell proper, must be independently supported on 1,000-mm-diameter pile foundations.
- Top pedestal and part of the main foundation raft must be dismantled and rebuilt with heat-resistant concrete (M30 grade) along with new holding down bolts to fix the upgraded equipment base and additional reinforcements, wherever required.
- After modification, the vertical load on the equipment foundation from the shell of the upgraded equipment must not exceed the original design load, that is, 21,000 Kips (9,258 tons).

2.4 Time Constraint for Shutdown of the Equipment

The entire rebuilding and upgradation process had to be done under a very tight time schedule. Since the work involved dismantling and rebuilding of part of the existing foundation, temporary shutdown of the equipment was necessary. However, in a running plant, shutdown of a major equipment is directly related to a loss in production and hence revenue. Thus, it was essential to minimise the shutdown period as far as practicable. A micro schedule was prepared to target a total shutdown period of 100 days, consisting of rebuilding of the furnace shell and other accessories to cater to the capacity enhancement. This period also included erection of steel tower and rebuilding of foundation. Period for dismantling and rebuilding of foundation proper was restricted to 14 days only.

To optimise the shutdown period to a minimum, it was decided to adopt controlled blasting technique for breaking/dismantling part of the foundation, as manual breaking would have taken an enormous amount of time. At the same time, one had to be extremely careful to ensure that the blasting process did not cause any distress or damage to the remaining portion of the structure, proposed to be retained intact. Based on these considerations and to address the uncertainties involved with the after-effects of blasting, it was decided to construct a model of the foundation system and carry out controlled blasting to simulate the actual conditions.

2.5 Model Foundation with Blasting to Simulate Results

As described in the preceding section, it was decided to carry out the trial blasting on a model foundation, similar to the actual equipment foundation, to have hands-on information about the effects of blasting on the portion of the foundation to be retained and reused. Accordingly, the following course of action was decided upon:

- To construct a scaled model foundation based on information gathered from unearthed data about the existing equipment foundation, that is, shape, size, grade of concrete and reinforcements.
- To carry out controlled blasting through 32-mm-diameter vertical holes, at 500-mm centres, circumferentially, in ring formations, with three (3) such rings at radial distance of 500 mm. Sequence of blasting would be from the outer to inner rings with suitable delay per charge.
- To drill 32-mm-diameter horizontal through holes, at 500-mm centres, at 250 mm above the octagonal mat for easy separation and arresting shock wave propagation down below.
- To record shock wave intensities during blasting, near the dismantling level of the model block, engaging suitable sensors.
- To carry out non-destructive/partial destructive tests on balance portion of model foundation block, intended to be retained, before and after blasting, to check for possible health deterioration.

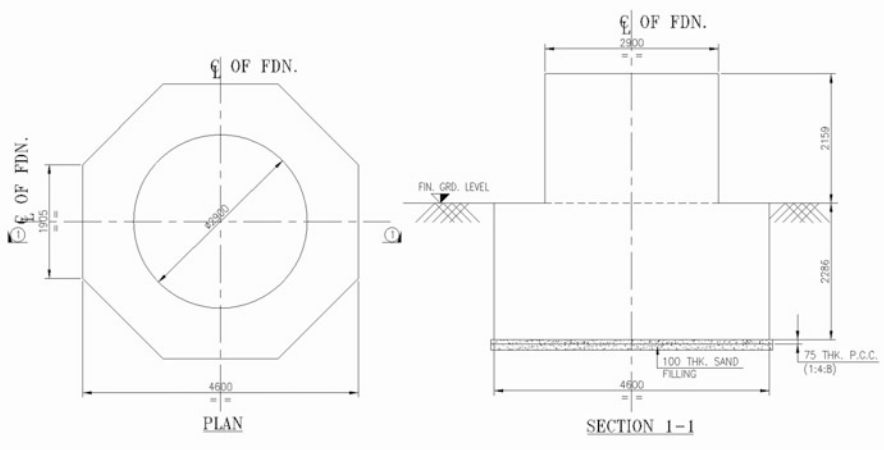


Fig. 4 Details of model foundation

- To simulate all recorded data on model foundation block with the prototype foundation block to ascertain different parameters for controlled blasting of the same and to restrict the disturbance below dismantling level to within acceptable limits.

Details of the model foundation are indicated schematically in Fig. 4 above.

Based on the above guidelines, controlled blasting was successfully carried out, on a model foundation, with extensive recording of data. Analyses of all recorded data led to the following conclusions:

- Results of core samples from octagonal mat before and after blasting did not indicate any deterioration of concrete strength due to the effect of blasting.
- Fragmentation of concrete was less in the area with reduced explosive charge, and the overburden on the pedestal was less than sufficient to contain the fragments from ejecting.
- The mat experienced mainly symmetric compression and a marginal amount of tension due to the effect of blasting. The compressive stresses were well within the allowable limits of concrete, and chances of cracking were remote due to insignificant tensile stresses.
- High vibration levels and high momentary shock-wave velocities were recorded, due to blasting, which were higher than the permissible values. However, these would actually subside to low levels due to attenuation characteristics of the soil surrounding the foundation.

The above observations and analyses of results were found to be quite encouraging thereby emboldening the concerned engineers to finalise dismantling of part of the actual equipment foundation by controlled blasting.

2.6 Dismantling Part of Existing Foundation

Based on the results and simulation studies of blasting of model foundation, actual controlled blasting of the prototype equipment foundation was done. To carry out this work, it was decided to maintain the disposition of vertical and horizontal holes and sequence of blasting in line with the model study. To minimise the critical shutdown period of the equipment, some activities were carried out in the pre-shutdown period, as preparatory work. These mainly included:

- Developing a plain cement-concrete horizontal base on which the reinforcement cage of the foundation pedestal was fabricated with erection framework, bolt sleeves and bolt boxes
- Fabricating lower erection framework followed by fabrication of the upper framework
- Providing permanent steel shuttering with 10-mm-thick steel plates and fixing the same with the reinforcement by welding arrangement
- Providing lifting hooks to each segment of the upper erection frame and strengthening the upper and lower erection frames by bracings to prevent buckling during lifting and transporting

During the initial phase of shutdown, some more preparatory works were done like construction of an RCC overlay on the vertical side of upper octagonal mat with dowel bars and bonding agent, horizontal drilling to create a cut-off plane and drilling about 10% of vertical holes on top of circular pedestal to facilitate blasting.

Dismantling of part of the existing foundation was done during the period allotted for rebuilding of the foundation that was limited to 14 days only to adhere to the schedule for total shutdown period of the furnace. During this period, the balance vertical holes were drilled, in staggered fashion, in a grid of 650 mm square. A temporary safety deck was also erected to act as a barrier for accidental fall of any object during activity above the deck. These were followed by installing the requisite explosive charge in the vertical holes (between 125 and 250 g per hole) and carrying out controlled blasting.

Blasting was carried out in four volleys with the total charge of the explosives being 42.5 kg. Adequate safety precautions were taken by placing sand bags all around the foundation as the operations were done within an existing plant. During blasting, the cylindrical pedestal was loaded with overburden weight of about 100 kg/m^2 to prevent the fragmented pieces from being ejected.

Controlled blasting proved to be a very successful venture. After the operation, it was noted that the total concrete above the octagonal raft could be removed easily leaving a smooth top surface of the octagonal mat. This was because the continuity of reinforcement was limited only along the periphery of the circular shaft and the central portion was actually filled with lean concrete. The resulting debris, post blasting, was cleaned by excavators and disposed to designated dump areas.

A sectional view of the equipment foundation proposed to be partly dismantled and rebuilt is shown in Fig. 5 below. The scheme of blasting along with disposition of blasting holes, sequence of blasting and details of charge placement in each hole is presented in Fig. 6 below.

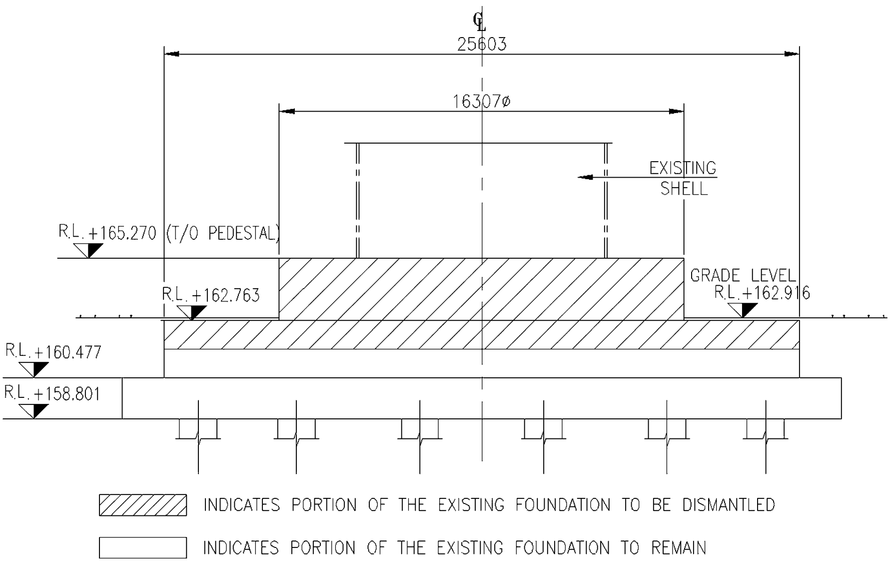


Fig. 5 Sectional view of foundation proposed to be partly dismantled and rebuilt

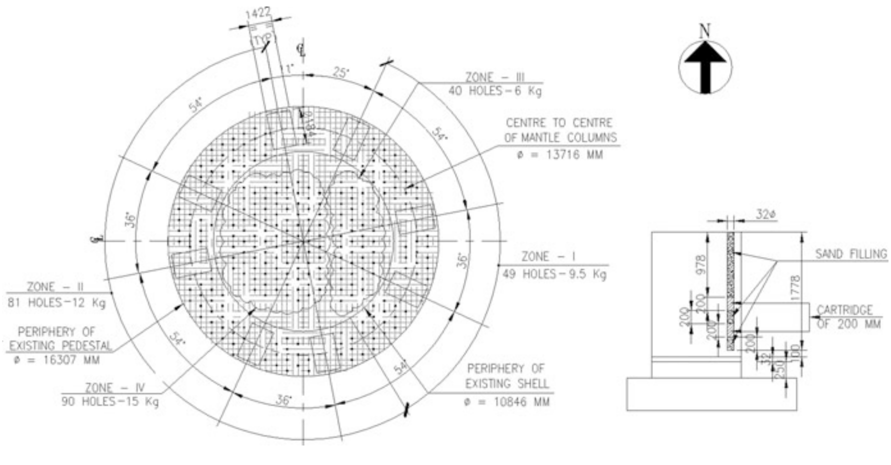


Fig. 6 Disposition of blasting holes, sequence of blasting and details of charge placement

2.7 Restricting Energy Propagation to the Base Raft

A major concern while planning the blasting activities was the propagation of shock waves to the lower portion of the foundation mat, intended to be retained and reused. To restrict wave propagation and avoid possible distress to the lower portion of the foundation mat, some kind of cut-off had to be planned. As indicated earlier, this was planned to be facilitated by drilling horizontal holes, through the cylindrical pedestal, at a suitable height above the top of the octagonal mat. This was implemented during the model study to simulate the actual conditions with extensive measurement of shock-induced strains in the concrete.

The model studies indicated that due to blasting, the vertical reinforcement bars of the cylindrical pedestal had bent outwards from the level of the horizontal holes. The bars held with them chunks of pedestal concrete in the lower portion near the horizontal holes. As a result of this, the level of separation was formed at 200–300 mm above the desired level. As a result of this experience, the vertical reinforcements of the pedestal were cut at the level of the horizontal holes before blasting to facilitate proper separation and fragmentation. Based on the above, a series of 32-mm-diameter horizontal holes were drilled, at 500-mm centres, at 250 mm above the octagonal mat for easy separation and arresting shock wave propagation down below.

After the actual controlled blasting of the prototype equipment foundation took place, the results were there for everyone to see. There were absolutely no signs of distress or crack on the lower portion of the octagonal mat that was planned to be retained. This proved that the series horizontal drill holes, provided at cardinal locations, were indeed effective in creating a cut-off plane for energy dissipation and preventing the shock waves to travel below.

2.8 Load Transfer Through Tower and Existing Foundation

As indicated earlier, an assessment of loading on the existing equipment foundation was done to gauge its present condition. It worked out that the foundation was already overstressed in excess of what it was designed for. Some telltale cracks on the foundation mat also bore testimony to this fact. Thus, there was no way the foundation could be loaded further as per the requirement of upgradation. The engineering solution that was needed to be developed was to design a system that would effectively transfer the enhanced load, from the upgraded equipment, without causing any distress to the foundation. The solution suggested was the following:

- The proposed upgraded equipment should be free-standing type accompanied by four (4) tower legs around the shell proper.
- The entire shell would carry its self-weight including the weight of refractories and weight of offtake, uptake, downcomer and the Compact Bell Less (CBLT) Top charging system.
- The four tower legs would carry, besides their self-weight, the weight of skip bridge, top structure and platforms at different levels.
- To facilitate the above, the main octagonal mat foundation was partly dismantled and rebuilt, as described in the preceding sections. The four (4) towers, on the other hand, were independently supported on 1,000-mm-diameter bored cast-in-situ piles of 300-t capacity each.

Sketches showing the plan and sectional elevations of the rebuilt equipment foundation are shown in Figs. 7, 8, and 9, respectively.

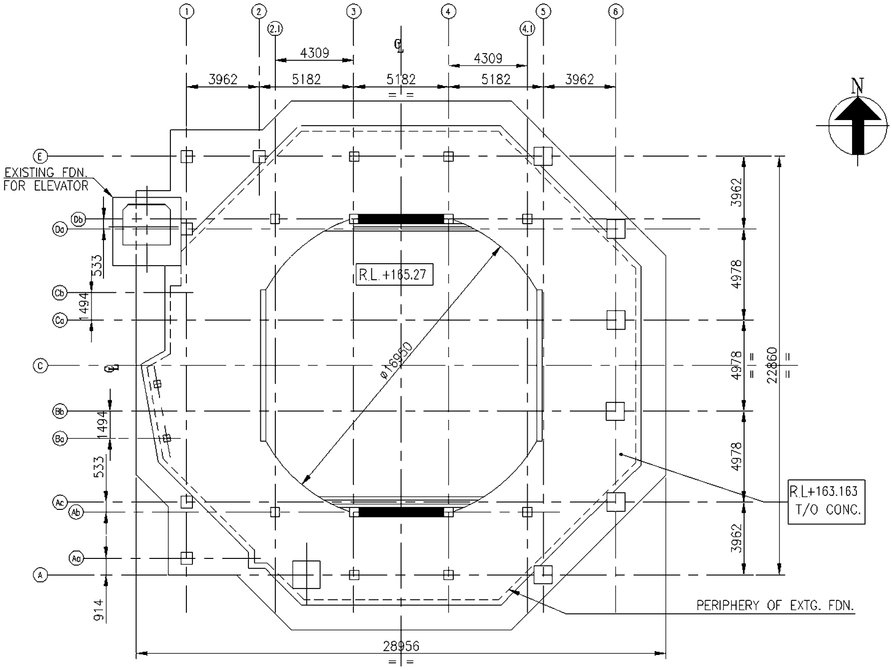


Fig. 7 Plan showing rebuilt equipment foundation

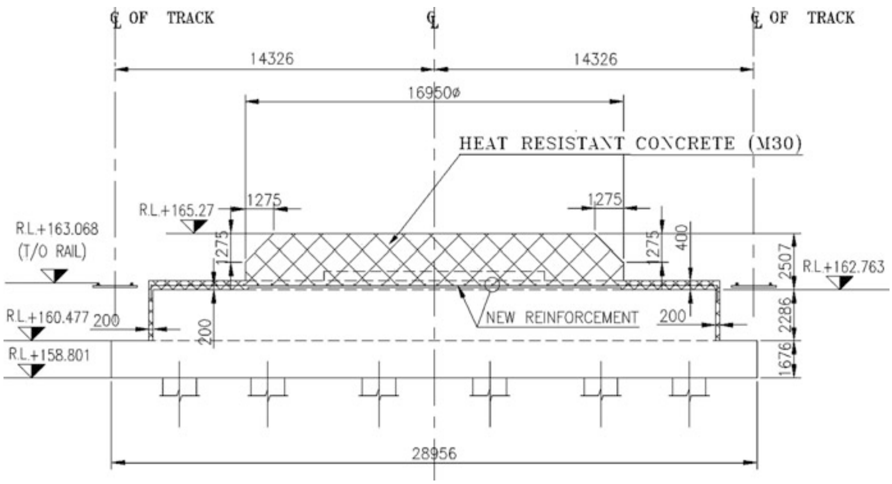


Fig. 8 View from west side showing rebuilt equipment foundation

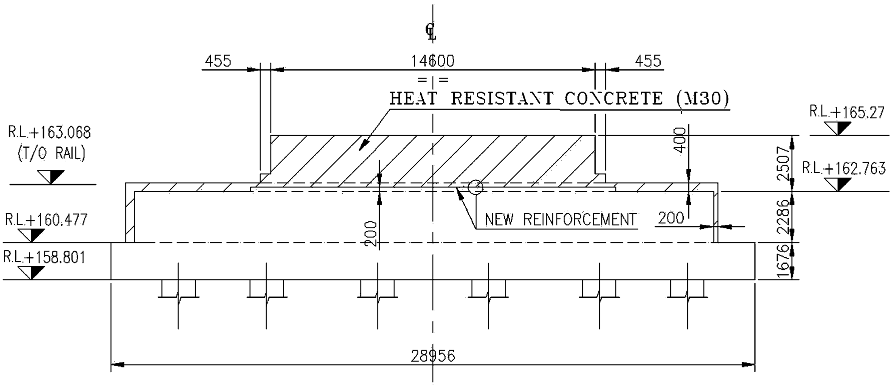


Fig. 9 View from south side showing rebuilt equipment foundation

3 Mitigating Uncertainties in Record Time

There were a number of uncertainties in every step of the rebuilding process that confronted the engineering team. Some of them have been highlighted in the preceding sections of this chapter. However, the biggest and by far the most challenging task was the race against time. As the work was being done in a running plant, any rebuilding and upgradation process necessarily required an optimum period of shutdown of the concerned equipment and some of the associated facilities. It goes without saying that shutting down of a major unit in a running plant hampers production and, consequently, has a direct bearing on revenue. To be fair to the clients, the shutdown period allowed for the work was extremely tight. It seemed impossible and somewhat improbable to complete all the activities within the very stringent time period that was allowed. However, with a dedicated design and construction team working in unison and perfect harmony, the target was achieved a couple of days before the scheduled completion date. The feat was duly recognised and appreciated by the clients in no uncertain terms.

An isometric view of the rebuilt and upgraded equipment foundation is shown in Fig. 10.

4 Conclusion

In a premier integrated steel plant of our country, a major production equipment was due for relining and refurbishment during the early part of the new millennium. However, the clients desired to upgrade the equipment at the same time to enhance their production capacity. This called for a detailed study of the existing foundation

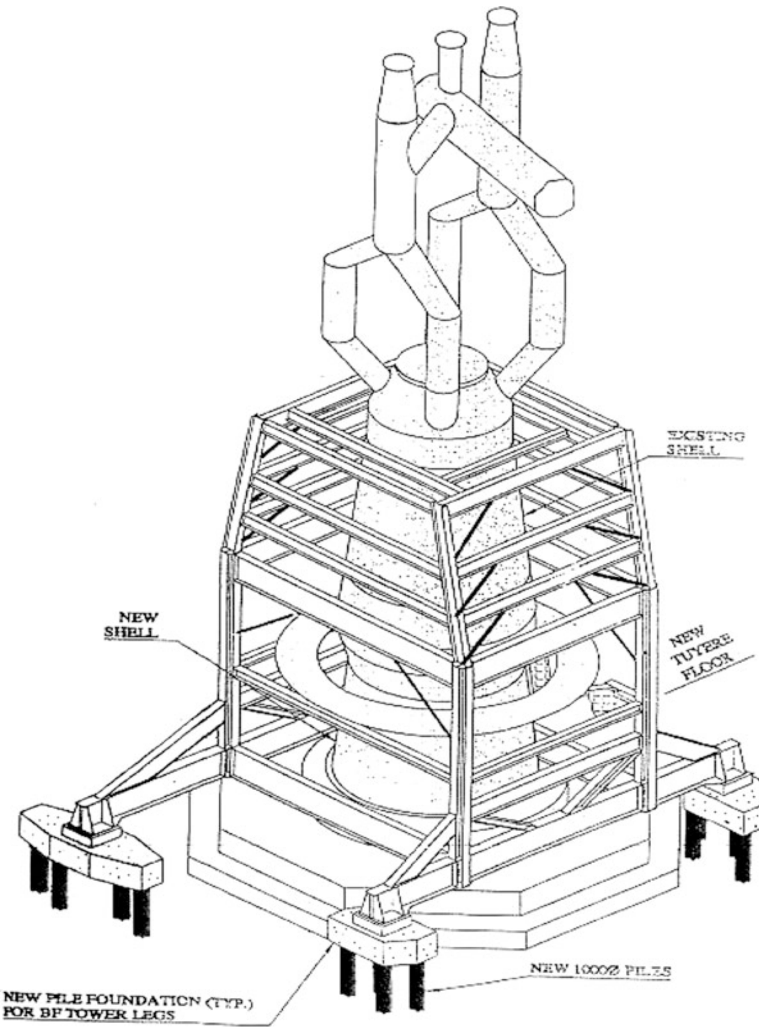


Fig. 10 View of rebuilt and upgraded blast furnace

system of the equipment to assess its feasibility of upgradation. Being constructed and commissioned more than four decades ago, there were very few data available regarding the foundation system of the equipment. A thorough search of the client's archives yielded rather insufficient and scanty data related to the equipment foundation. A team of engineers did a feasibility study based on whatever data could be unearthed and some innovative engineering to develop a workable scheme of rebuilding and upgrading the equipment. There were multiple uncertainties involved in every stage of the work. However, through meticulous planning, brain storming and model studies to simulate results and some innovative engineering, these uncertainties were overcome to reach levels of relative certainty in each and every stage. The equipment was rebuilt and upgraded in record time and handed over to the clients to start production to its planned enhanced capacity.

> So what do we do? Anything. Something. So long as we just don't sit there. If we screw it up, start over. Try something else. If we wait until we've satisfied all the uncertainties, it may be too late. Lee Iacocca