Design Manual
Improved Fixed Chimney Brick Kiln

MinErgy

Greentech Knowledge Solutions Pvt. Ltd.

Response to Earthquake: Rebuilding Nepal's Brick Industry

Design Manual

A technical guide on how to design Induced Draught and Natural Draught Zig-Zag Kilns

Supported by

Disclaimer

The methods described and recommended in this manual are based on research and consultation with experts by Minergy Pvt Ltd and Federation of Nepal Brick Industries (FNBI). This manual is expected to serve as a basic tool for construction engineers and supervisors to delineate the essential parameters for the construction of an Induced as well as Natural Draft Zig-Zag kilns. However, there are unique features for most brick kilns and kiln sites, so no single design recommendation is appropriate for all kilns. Thus, the proposed design has been developed for particular conditions, as described under the respective headings, recognizing the inherent variability that exists in Nepal. The user should utilize this guide as a reference to support kiln improvements. The authors, publishers or any legal entity or person associated with this design manual disclaim any responsibility (legal, social or financial) for any adverse conditions/consequences resulting from the suggested procedures, from any undetected errors, or from the readers misunderstanding of the text.

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Message

Each year, an estimated 4 to 5 billion bricks are produced from more than 700 brick kilns in Nepal. The brick industry is one of Nepal's largest industrial sectors, and it contributes significantly to both industry and construction. However, in Nepal the brick industry is still an informal sector, and it is facing many challenges related to energy efficiency, environmental protection, and technological development. The 7.8-magnitude earthquake in April 2015 damaged 312 brick kilns across Nepal, with all of the kilns in the Kathmandu Valley heavily affected.

After the earthquake, people across Nepal have demonstrated their resilience and ability not only to respond, but to build back better. This new design manual for brick kilns is one example of this. Brick entrepreneurs watched the earthquake and its aftershocks destroy their kilns and livelihoods, and then swiftly responded. Within this response, the principle of 'building back better' has become a guide for ensuring that brick kilns are rebuilt stronger, smarter, and cleaner.

The Ministry of Industry is pleased with the collective efforts of the Federation of Nepalese Brick Industries (FNBI), ICIMOD, Climate and Health Research Network (Chern), and MinErgy to develop a brick kiln design that is more earthquake resistant, energy efficient, and environmentally friendly. This effort has been further strengthened through the inclusion of a team of brick experts from South Asia, brick kiln owners, environmentalists, architects, and civil , structural, and mechanical engineers in the development of the improved brick kiln design.

The Ministry of Industry seeks to play a key role in modernizing the brick kiln industry in Nepal. This design manual provides a path for smarter brick production that is able to resist future earthquakes, use less fuel, produce better bricks, and emit fewer pollutants, all while meeting the high demand for building materials expected in the coming year.

We are grateful that the Federation of Brick Industries took on this initiative at this critical juncture. This manual represents the integration of on-the-ground knowledge and engineering expertise. It is also a living document, and, as entrepreneurs begin using it to guide the reconstruction of their kilns, the Ministry asks that thelessons learned be captured for future use.

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FNBI was established in 2007 for the development of brick industries in Nepal and welcomes technological advancement for its betterment. However, FNBI is also aware of its members' capacity and seeks to ensure that the technological advancement suits the local soil and aligns with limitation of entrepreneurs. TRDC has been instrumental to bridge this need with technology partners and donors directly with FNBI since its inception in 2014. Its approach as an R&D unit of FNBI has proven that the methodology of engaging best practicing entrepreneurs themselves as trainers is most effective in the technology transfer and implementation process.

The earthquake has awakened all entrepreneurs on the engineering aspects and technical knowledge that was lacking in the traditional construction of the kilns. FNBI feels proud to be part of this exemplary collaboration comprising local experts, national engineers, scientists and architects with external advisory reviews by international experts in this study which has been first of its kind in entire South Asia. FNBI would like to acknowledge the hard work from the technical team and contributors of this manual who have ensured the best seismic resistant design and also takes into account energy efficiency, environment and other social aspects for rebuilding Nepalese brick kilns. Scientific study of seismic considerations, energy efficient practices inbuilt in the design, along with guidelines and tips on addressing OHS issues and reducing negative emissions points towards the expected outcome of this design manual.

FNBI would like to thank and acknowledge MinErgy for technical assistance and introducing the project with support from CHeRN USA at a time when we were deeply concerned with the loss and the need to rebuild the damaged industry. We would also like to acknowledge Bidya Banmali Pradhan for coming forward with ICIMOD's assistance in technical input, publication of this manual and bridging the policy gap.

Lastly, we urge all brick kilns throughout Nepal to adopt this design manual wherever possible, as FNBI shall provide the design manual along with voluntary supervision and technical assistance. FNBI will continue to organize relevant training programs for firemen and entrepreneurs to make brick industries economically sustainable, energy efficient, environment friendly and contribute to economic growth in nation building. We also look forward to continued collaborative support from our government donor and partner organizations in our upcoming initiatives.

अध्यक्ष

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Message from CHeRN

The Climate and Health Research Network (CHeRN) was honored to be able to provide support to the work that has gone into the preparation of *this Design Manual for Improved Fixed Chimney Zig-Zag Brick Kiln*. Here was an example of a teamwork approach to seriously direct attention on meeting multiple goals: providing building materials, while improving energy use, reducing air and climate pollutants and making future brick kilns more earthquake resistant. This product shows the benefits of bringing together multiple skills and knowledge to deliver the best work possible.

This manual has pushed the collective thinking of the industry in very positive ways. As entrepreneurs begin adopting the new designs, the knowledge base will deepen, and every effort will be made to captured and pass on new information.

Special thank goes to the Federation of Nepal Brick Industries, its Technology Research and Development Committee, MinErgy, Greentech Knowledge Solutions Pvt. Ltd. and ICIMOD. This work would not have been possible without a rapid response from the Pisces and Climate Works Foundations.

Ellen Baum
Director
Climate & Health Research Network

ICIMOD

FOR MOUNTAINS AND PEOPLE

Message – Director General, ICIMOD

During the April 2015 earthquake in Nepal, in addition to hundreds of thousands of houses and buildings that were destroyed, hundreds of brick kilns, including the majority of those in the Kathmandu Valley, were damaged. As the country rebuilds, bricks – the preferred construction material in Nepal – will remain in high demand.

The use of large quantities of coal in brick kilns contributes significantly to the emission of numerous air pollutants, including carbon dioxide, black carbon, sulphur dioxide, and carbon monoxide. These affect the health of brick kiln workers, people living in cities nearby, and the rest of the region, and also contribute to global warming.

After joining the Climate and Clean Air Coalition (CCAC) in 2012, ICIMOD has been actively involved in the coalition's brick production initiative, leading the initiative's work in Asia. Through this initiative, we were already working with the Federation of Nepal Brick Industries (FNBI) on policy advocacy, establishing training nodes, developing instruments for measuring emissions in kilns when the earthquake struck Nepal.

Our existing collaboration with CCAC and FNBI has given us the chance to turn this crisis into an opportunity. Together with MinErgy, we have developed a manual that will help rebuild this sector in a cleaner, and more environmentally friendly manner. This manual is the first of its kind in South Asia. And the process of preparing this manual has included input from local brick experts and entrepreneurs, national engineers, scientists, and architects with advisory reviews by international experts.

I would like to thank FNBI, MinErgy and the entire team for their hard work in quickly developing this manual. Along with our partners ICIMOD hopes that, through this manual, we can encourage brick kiln entrepreneurs in Nepal and across the Hindu Kush Himalayan region to invest in improved kilns that are more energy efficient and produce less pollution. The new, simple brick kiln technology described in this publication will not only help improve air quality in the region, it will also increase the profitability of brick enterprises and provide consumers with better quality building materials.

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Preface

This design manual is a first attempt at understanding and describing the robust structural design of brick kilns to rebuild kilns in the "right way". The need for development of such design has arisen in response to the structural damages that occurred to brick kilns from the7.8 magnitude earthquake that hit Nepal in April 2015. In the past, the majority of Nepal's brick kilns were constructed in a rudimentary style, without considering the appropriate engineering knowledge. That is the reason why most of the kilns did not withstand the impact of the earthquake.

Despite the losses and damages, the earthquake on 25thApril 2015 has provided a unique opportunity to rebuild in the right way. Brick stakeholders have collaborated to create a robust structural design of the fixed chimney brick kilns that takes into account seismic strength, fuel requirements, air pollution burden and other social aspects for rebuilding Nepalese brick kilns. This is the right time to correct past designs, improve flaws, consider what was missing and develop a better and stronger structure. The new kilns will be structurally safe, earthquake-resistant, energy efficient, lower emitting, worker-friendly and able to produce better quality bricks.

To achieve this goal, MinErgy Pvt. Ltd. and FNBI worked together with Greentech Knowledge Solutions Pvt. Ltd. and a technical committee, comprised of brick kiln experts and entrepreneurs from Nepal and India. The team began work shortly after the earthquake and worked intensively to produce this manual. The design incorporates both practical experiences and scientific analysis for both Induced and Natural Draught Zig-Zag Fixed Chimney Brick Kiln. This manual includes engineered designs; two supplementary documents provide drawings and construction guidelines.

This project is supported by Climate and Health Research Network (CHeRN)/USA and International Center for Integrated Mountain Development (ICIMOD).

The authors seek ideas and work experiences to further improve this design manual for a subsequent version, should one be deemed appropriate.

Federation of Nepal Brick Industries/Nepal
MinErgy Pvt. Ltd/Nepal
Greentech Knowledge Solutions Pvt. Ltd/India

Acknowledgement

In developing this manual, every effort was made to include the existing knowledge base, along with the inputs from interactions among experts and professionals associated with Zig-Zag technologies. Also, there have been contributions from wider network of people associated with brick industry.

Hence, we would also like to acknowledge the support of various individuals and organizations who have contributed in various ways during the process of developing this design manual.

To start with, our heartfelt thanks to our funding partners the Pisces Foundation and Climate Works Foundation, Climate and Health Research Network (CHeRN)/USA, Climate Change and Clean Air Coalition (CCAC) and International Center for Integrated Mountain Development (ICIMOD). Specifically, we would like to extend our gratitude to Ms. Ellen Baum, Director, CHeRN/USA and Ms. Bidya Banmali Pradhan, Associate Coordinator - Atmosphere Initiative (Water and Air), ICIMOD. We thank Ms. Pradhan for also Co-Chairing the Technical Committee of this project and the Atmosphere Initiative team for providing design inputs for this manual. Secondly, we would like to thank Mr. Mahendra Bahadur Chitrakar, the President, Federation of Nepal Brick Industries (FNBI) for leading the Technical Committee of this project as a Chairperson. Particularly, we are grateful for the valuable inputs of Brick Entrepreneurs, Mr. Shyam Maharjan, Mr. Rajendra Maharjan, Mr. Rajkumar Lakhemaru and Mr. Mangal Krishna Maharjan. Also, we are thankful to Mr. O P Badlani and Mr. Sandeep Ahuja for bringing practical design insights from India.

Similarly, we would like to thank Ms. Usha Manandhar, Program Director, Better Brick Nepal project for her support and valuable inputs to develop this manual. Also, we would like to thank Dr. Sunil Joshi, Occupational Health and Social (OHS) expert, for providing knowledge on the OHS issues. Also acknowledgement is for Prof. Dr Rajan Suwal, Senior Structural Engineer, for his valuable inputs in reviewing the design with structural and seismic safety aspects.

We would like to acknowledge sincere efforts of Mr. Raj Kumar BK, Mr. Santosh Gautam, Mr. Santosh Ranabhat and Mr. Sujit Kafle (Mechanical Engineering Students) for their inputs on the impeller fan design. We extend our special thanks Mr. Sikhar Rai, Mr. Ashesh Babu Timalsina and Mr. Aditya Neupane for their valuable inputs in carrying out Computational Fluid Dynamics (CFD) analysis. Last but not the least; we recognize Mr. Rajesh Bajracharya and Ms. Sabina Giri for their excellent logistics management.

Acronyms

BCN	Brick Clean Group Nepal
BOQ	Bill of Quantity
C/C	Centre to Centre
CCAC	Climate and Clean Air Coalition
CFD	Computational Fluid Dynamics
CHeRN	Climate and Health Research Network
CV	Calorific value
EA	Excess Air
FCBTK	Fixed Chimney Bull's Trench Kiln
FNBI	Federation of Nepal Brick Industries
Ft	Feet
ICIMOD	International Center for Integrated Mountain Development
IDZZK	Induced Draft Zig-Zag Kiln
kCal/kg	Kilocalorie per Kilogram
kg	Kilogram
kg/s	Kilogram per second
kN/m^3	Kilo Newton per cubic meter
kW	Kilowatt
m	Meter
m/s	Meter per second
MJ	Mega joule
MJ/kg	Mega joule per kilogram
mm	Millimeter
NDZZK	Natural Draft Zig-Zag Kiln
oC	Degree Celsius
OHS	Occupational Health and Safety
PM	Particulate Matter
RC	Reinforce Concrete
SEC	Specific Energy Consumption
SOx	Sulphur Oxides
SPM	Suspended Particulate Matter
WG	Water Gauge
ZZK	Zig-Zag Kiln

Note : Acronyms used in the technical calculations are described in the respective chapters.

Glossary

The glossary contains only the commonly used terminologies in brick kilns.

Assam Coal	A high volatile, high sulphur and high calorific value bituminous coal mined from Assam State in India
Chamber	A batch of bricks in-between baffle in the dug
Dug	Space between outer and inner wall of the kiln where bricks are stacked for firing
Gali	The narrow space between outer and inner wall towards two end of the kiln
Jharia Coal	A medium to high ash content, medium volatile bituminous coal.
Main Nali	The main duct through which flue gases flows towards the chimney
Miyan	The structure in between the kiln that covers the main ducts
Petcoke	Petcoke or Petroleum coke is a carbonaceous solid delivered from oil refinery coker units or other cracking processes
Shunt	A shunt is a metal duct, which is used to connect the central duct of the chimney with the side ducts.
Side Nali	The duct or inlet that connects dug and the main nali
Surkhi	The fired brick dust used as insulation to cover bricks on the dug
Vertical Hall/Mangaal	A vertical rectangular structure that serves as connector between side and main nali with a shunt
Wicket Gate/ Dwari	The opening on the outer wall from where bricks are transported to and from the dug

Table of Content

List of Table

List of figures

This manual is divided into three parts. **Part A** provides an overview and context on the needs and objectives of the design manual. This also covers the background of brick kiln and firing technology. **Part B** provides the background on the technical design of brick kiln components. **Part C** provides the detail technical analysis as well as the designs of different kiln components.

PART A – Introduction to Manual

1 Background

The severe earthquake that hit on 25th April has caused extensive infrastructure damage in Nepal. It has damaged houses, commercial buildings, heritage sites, hospitals, schools government offices, and roughly 350 of the country's 800 brick kilns. Over 100 of the kilns that were affected are located in three districts within Kathmandu Valley: Kathmandu, Bhaktapur and Lalitpur. The structural damages observed include broken chimneys, damaged outer walls (of firing zone) and Miyan walls (inner walls of firing zone). Almost all kilns within the valley and many outside need major maintenance or retrofits to operate in the upcoming brick making season.

Further, post earthquake, government estimates brick demand will increase to twelve billion, almost four fold more than 2013 and 2014 production. To cater to the higher demand, many brick entrepreneurs would like to rebuild fast and in the right way. The demands for restoring and rebuilding brick kilns that can better meet Nepal's immediate building and environmental needs, and withstand future earthquakes allowed a team of country and regional experts to come quickly together. The short time during the early monsoon season offered a focused opportunity to develop kiln designs that could be structurally safe, less polluting, energy efficient and better for workers.

The final product is the design manual and two supplementary documents with detailed drawing and construction guidelines for Induced Draught Zig-Zag Kiln (IDZZK) and Natural Draught Zig-Zag Kiln (NDZZK).This manual is expected to serve as a tool for construction engineers and supervisors. It describes essential parameters for the design and construction of IDZZK and NDZZK.

2 Objectives

The objective of this design manual is to support the Nepalese brick industry to build and operate brick kilns that are:

- Earthquake-Resistant
- More Energy Efficient
- Environmentally Friendly (Low-emitting)

3 Overview of Fixed Chimney Brick Kiln

The Fixed Chimney Bull's Trench Kiln (FCBTK) technology is the most widely used technology for firing bricks in South Asian countries. It is a continuous, moving fire kiln in which the fire is always burning and moving forward in the direction of air flow, due to the draught provided by a chimney. The bricks are warmed, fired and cooled simultaneously in different parts of the kiln. It is a modified version of Bull's Trench Kiln introduced by a British engineer W. Bull in 1876.

There are basically two types of FCBTK in operation. They are force/induced draught and natural draught. In forced or induced draught, a fan is provided to create the draught from the chimney whereas in natural draught, the chimney itself creates the required draught.

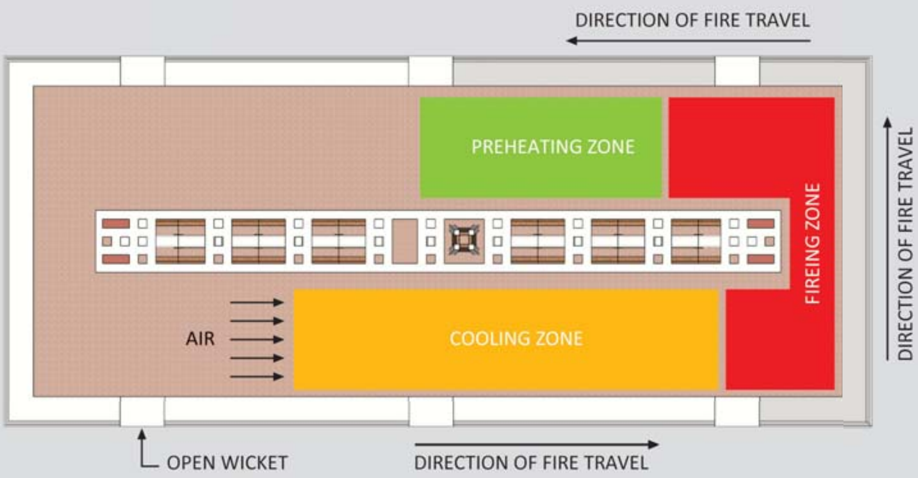
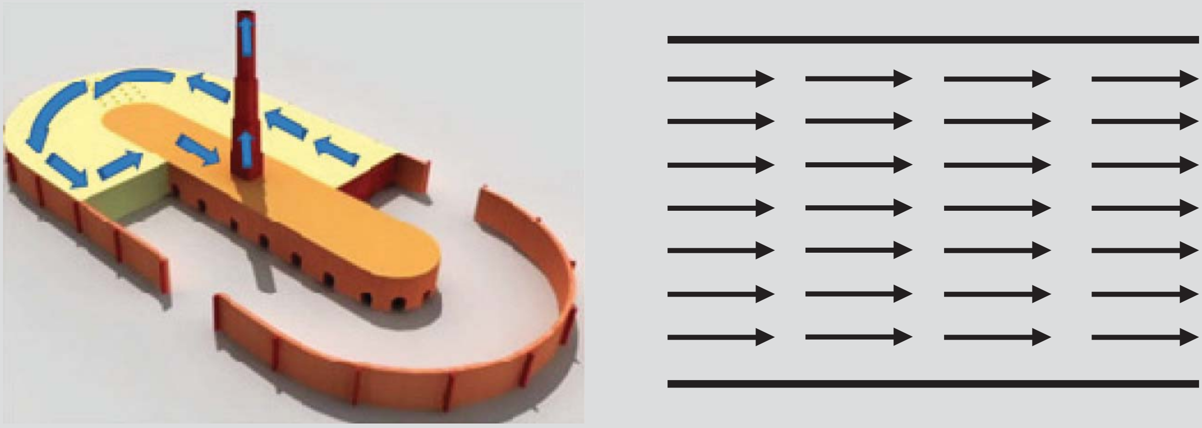


Fig 1 – Schematic illustration of operations and firing zones of fixed chimney kiln

Based on the brick setting pattern, induced and natural draught can be further classified as straight line or zig-zag kiln. In a straight-line, air flows in a straight path whereas in a zig-zag kiln, the air moves in a zig-zag path. The length of the zig-zag airpath is about three times longer than the straight-line air path. The increased air velocities in the kiln, the turbulence created due to the zig-zag air movement, and the longer air path result in improved heat transfer between air/flue gases and bricks thus making it more efficient. Induce draughts are generally zig-zag, whereas natural draughts can be either straight-line or zig-zag.

Fan operated FCBTKs, though commonly named forced draught, is actually based on the induced draught principle where a fan is at the exit end of the flow path pulling hot air from the duct to the chimney. Hence, in this manual the term induced draught is used instead of forced draught.

Straight Line Firing



Zigzag Firing

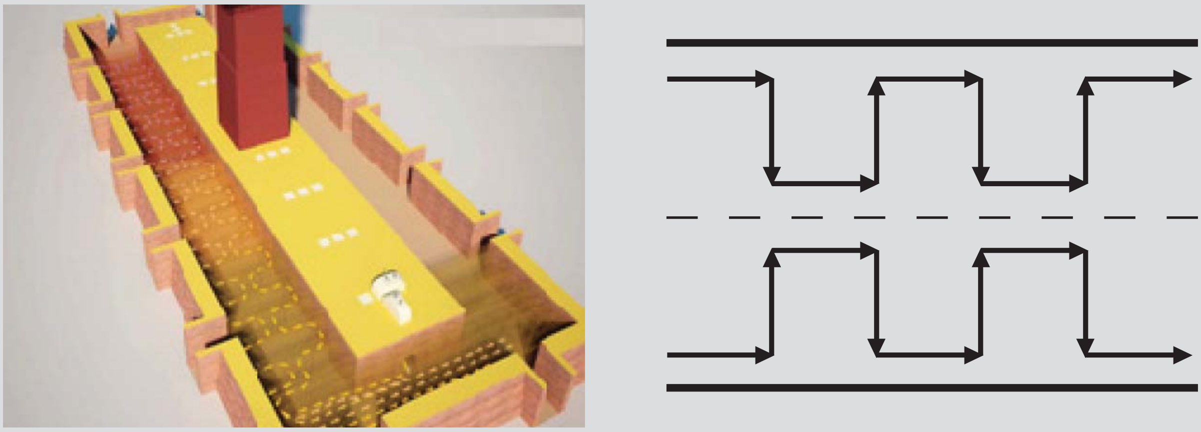


Fig 2 - Air flow patterns in the straight line and zig-zag fixed chimney brick kiln

PART B – Background of Kiln Design

4 Basic Design Parameters

The basic parameters that determine the design specifications of different kiln components are identified and analyzed. Following basic parameters are considered while designing both the IDZZK and NDZZK in the design and calculations. Some design parameters are considered based on scientific theory and some based on decisions in the consultation forum of brick kiln entrepreneurs, FNBI and the technical committee.

Table 1 – Basic design parameters

S.No.	Parameters	Value	Justification
a. Common for both IDZZK and NDZZK			
1	Size of fired bricks	230 x 110 x 55 mm	Average size of standard bricks of Kathmandu Valley (Ktm-size brick).
2	Fired brick weight	2.1 kg	Average weight of Ktm size fired brick.
3	Green brick weight	2.25 kg	Average weight of Ktm size green brick.
4	Specific Energy Consumption (SEC)	1.1 MJ/ kg of fired brick	The average SEC in zigzag kiln is generally between 0.95-1.15 MJ/kg of fired brick The maximum value of SEC is taken for Zthe worst case scenario when the fuel consumption is high (e.g. during initial round of firing)
5	Heating value of coal	5500 kcal/ kg (22.99 MJ/kg)	Reference value of heating value is an average value taken from numerous sample of coal
6	Air quantity for burning per kg of coal	8.52 Kg of air/kg of coal	Stoichiometric air calculated for above mentioned coal
7	Moisture content in dried green bricks	7.5%	Annual average varies from 5-10 % usually
8	Flue gas temperature	100°C	Flue gas temperature at inlet varies from 80°C to 120°C
b. For IDZZK			
9	Daily production capacity	70,000 bricks per day	Design production capacity of kiln agreed by technical committee
10	Excess Air	300%	Value determined by numerous tests conducted for a well designed kiln in which leakage is controlled
11	Air flow velocity	5 m/sec	Velocity in the flue gas duct
c. For NDZZK			
12	Daily Production Capacity	50,000 bricks per day	Design production capacity of kiln agreed by technical committee

13	Excess Air	250%	Value determined by numerous tests conducted for a well designed kiln in which leakage is controlled
14	Air flow velocity	3 m/sec	Velocity in the flue gas duct

5 Kiln Components

The design manual consists of detailed design of the following kiln components. These kiln components are the key parts that in combination allow the functioning of kiln for brick firing. These key components are also important for making brick firing energy-efficient as well as less emitting. The detailed descriptions of each of these components are explained in the corresponding chapters of this manual.

- Kiln dimension
- Flue duct and inlets
- Kiln wall structure
- Wicket gate
- Chimney
- Floor

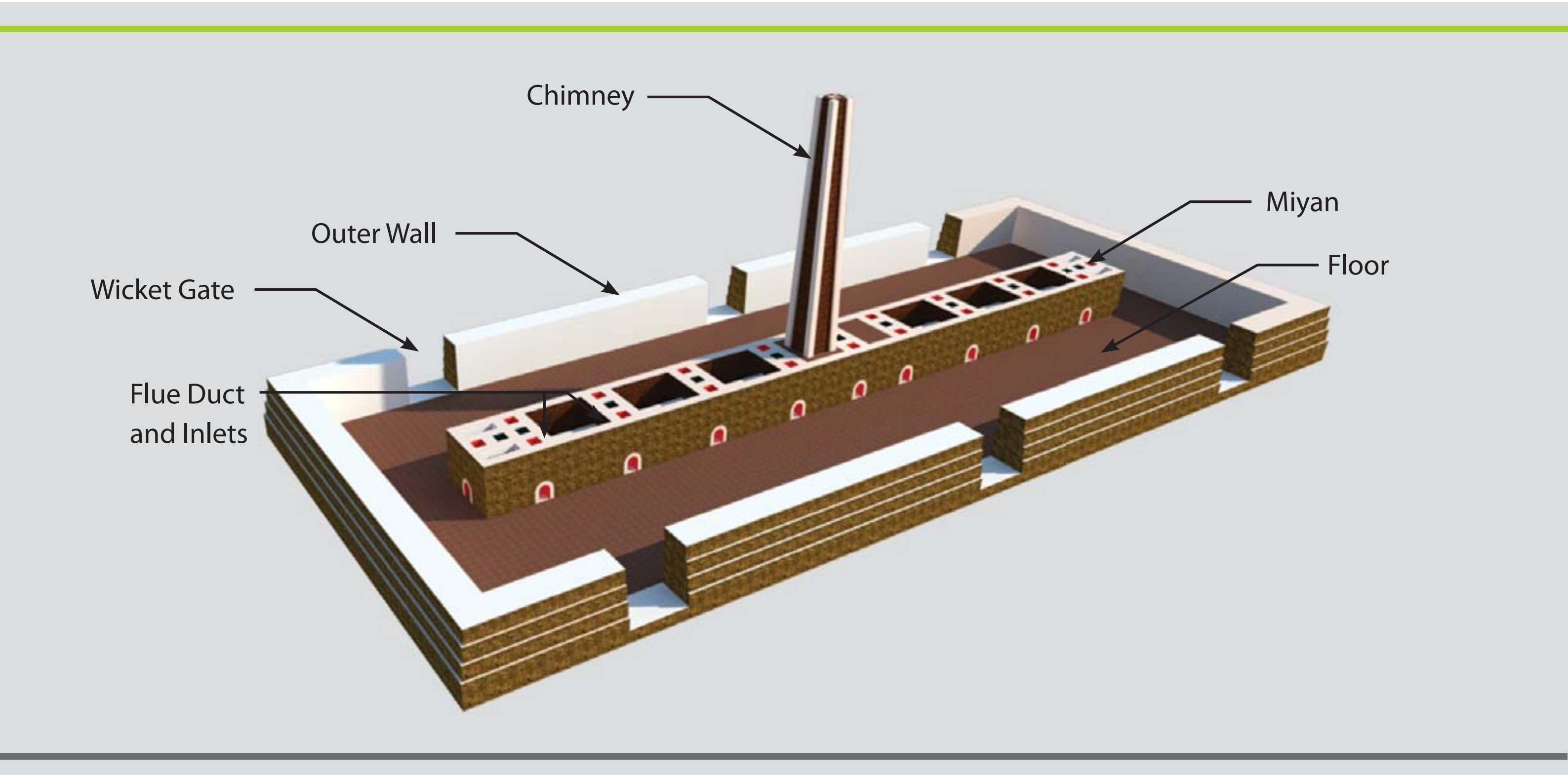


Fig 3 – Kiln diagram with design components

PART C – Kiln Design

6 Kiln Dimension

In general, there are different sizes of zig-zag kilns constructed in Nepal as well as in the South Asian region. There is no consistent design methodology to calculate the length and breadth of the brick kiln. The existing kilns in the region have different range of kiln dimensions where the length varies from 150 feet to 250 feet, whereas the width varies from 50 feet to 100 feet. Similarly, the available dug width has been found from 16 feet to 40 feet in Nepal. The size of kiln depends upon various factors like the production capacity of kiln, land availability, the requirements of kiln owner, etc.

Theoretically and practically, it has been found that the smaller-sized fixed chimneys are more energy efficient than kilns with larger dimensions. The operation becomes more efficient in the smaller kiln due to a shorter firing cycle. The energy consumption is highest in the very first round of operation, which continues to decrease in every next round until the stabilized condition is reached. After a few rounds of firing, the kiln operates with optimum fuel consumption. The stabilization can be achieved faster with smaller size kiln. Similarly, initial construction and maintenance costs are lesser for smaller kilns.

Despite all the benefits of the smaller kiln, brick entrepreneurs prefer bigger and larger kiln dimensions because:

– It works as the storage yard for green bricks
– It ensures smooth operation during the climatic disturbance, like rain
– Since, larger kilns produce in higher volume, it ensures the continuity of brick supply to fulfill market demand, even during shortage of labor or strike

The basis for determining the kiln dimension is brick dimension. The design of the kiln dimension consists of the dimension of various kiln components. The most important kiln components considered during the design process are:

- Dug width
- Dug wall height
- Chamber length
- Side nali spacing
- Gali width
- Miyan dimension
- Kiln outer dimension

The dimensions for key kiln components are proposed in Table 2. The justification and detail calculations for proposing these dimensions are discussed in the subsequent chapters.

Table 2 – Kiln dimensions of IDZZK and NDZZK

Dug width	28 feet	22 feet
Dug wall	10 feet	10 feet
Chamber width	6 feet	6 feet
Chamber Spacing	18 c/c	18 c/c
Gali width	14 feet	11 feet
Miyan Length	156 feet	156 feet
Miyan Width	16 feet	16 feet
Kiln Outer Length	197 feet	191 feet
Kiln Outer Breadth	85 feet	82 fee

6.1 Dug width

The dug width is defined by brick dimension, and the daily production needed. There are two methods, which can be followed to define the dug width:

- Dug width defined by brick dimension and brick stack length
- Fixing the dug width and adjusting the brick stack pattern accordingly

Since, the brick size varies from kiln to kiln, in order to generalize the design, the second methodology is followed. The design team, in consultation with brick entrepreneurs, has proposed **28 feet wide dug** for IDZZK with production capacity of 70,000 brick per day. Similarly for NDZZK **22 feet wide dug** has been proposed with production capacity below 50,000 bricks per day.

6.2 Dug wall height

The dug wall/ miyan wall height is the height measured from the dug surface. The dug wall is generally 10 feet high for almost all kilns. Hence, a **10 feet high dug wall** is proposed. The dug wall height remains the same for induced and natural draft zig-zag kilns.

6.3 Chamber length

In general practice, the length of the chamber varies from 6 feet to 9 feet. The better zig-zagging of air flow can be achieved by decreasing the length of the chamber. Hence, **6 feet long chambers** are proposed for both induced and natural draft zig-zag kilns.

6.4 Side nali spacing

The side nail is a flue inlet component, which is spaced in a regular interval along the length of Miyan. The spacing is defined by the length of chamber. In case of a 6 feet long chamber, the side nali is placed at the center of every 3rd chamber, i.e. the spacing is **18 feet center to center**. The spacing remains the same for induced and natural draft zig-zag kilns.

6.5 Gali width

The Gali is a narrow section of either edge of the zig-zag kiln, which is always narrower in width than the dug width. The existing zig-zag kilns have its Gali section with 8 feet to 14 feet width. To optimize the kiln design, the Gali width will be taken as half of the dug width. Hence, the Gali width for the induced draft zig-zag kiln is **14 feet** and for the natural draft zig-zag kiln, **11 feet** is proposed.

Gali width	=	*Half of Dug width*
Gali width for IDZZ	=	*0.5 x 28*
	=	***14 feet***
Gali width for NDZZ	=	*0.5 x 22*
	=	***11 feet***

6.6 Miyan dimension

There is no reference basis for sizing the Miyan dimension. To make the kiln efficient and compact, a smaller length is preferred. Hence, the design team proposed adopting the Miyan length of 156 feet, which is based on the best operating kiln of Mr. OP Badlani, India. This size also addresses the need of local brick kiln owners. The width of the Miyan also varies, which should at least accommodate the base of chimney. Generally, the Miyan width varies between 16 feet to 30 feet. In the design, a Miyan with 16 feet width is sufficient to accommodate the chimney foundation. Hence, **16 feet wide** Miyan has been proposed for induced and **26 feet wide Miyan** for natural draft zig-zag kilns.

6.7 Kiln outer dimension

The kiln outer dimension can be calculated simply adding dug width and gali width in Miyan wall dimensions.

[1] *Firing curve is the total length of firing cycle which consists of cooling zone, firing zone and preheating zone*

Length of kiln (excluding outer wall thickness)	=	*Length of Miyan + 2 x Gali width*
	=	***184 feet (for both IDZZK and NDZZK)***
Breadth of kiln (excluding outer wall thickness)	=	*Width of Miyan + 2 x Dug width*
	=	*16 + 2x28*
	=	***72 feet (for IDZZK)***
	=	*26 + 2x22*
	=	***72 feet (for NDZZK)***

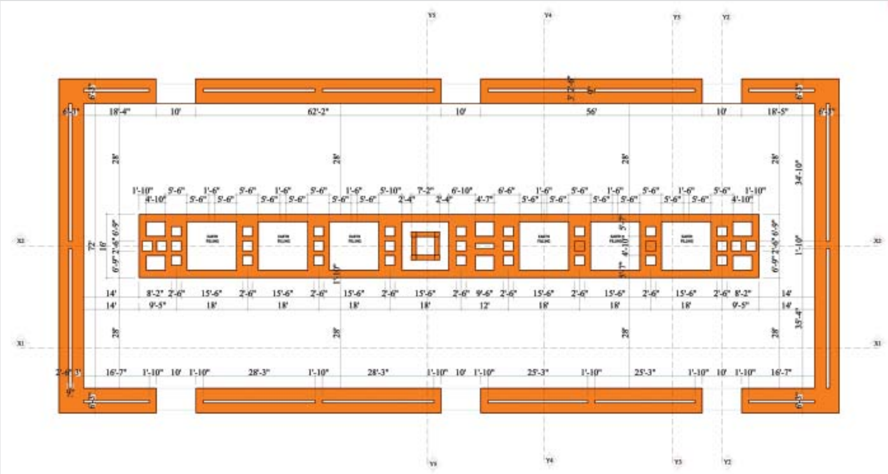


Fig 4– Induced draught zig-zag kiln plan

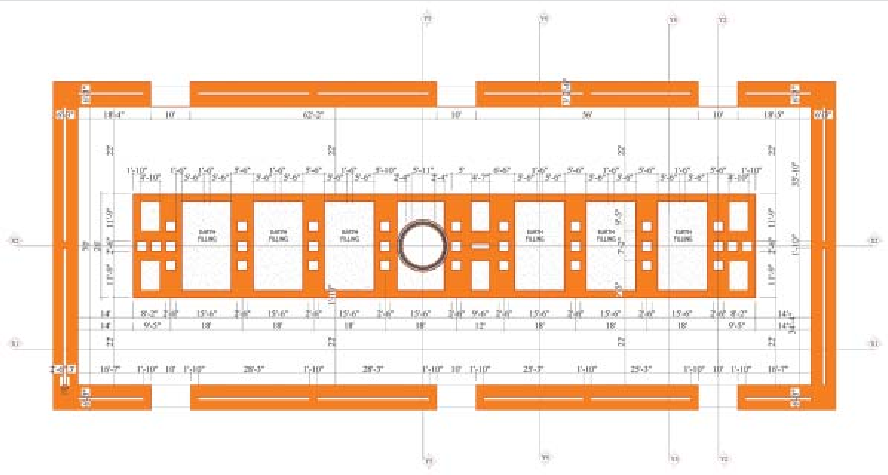


Fig 5 – Natural draught zig-zag kiln plan

7 Flue Duct System

The flue duct system consists of designing the size and dimensions of following components:

- Main nali (main flue gas inlet)
- Side nali (side flue gas inlet)
- Vertical hall/Mangaal

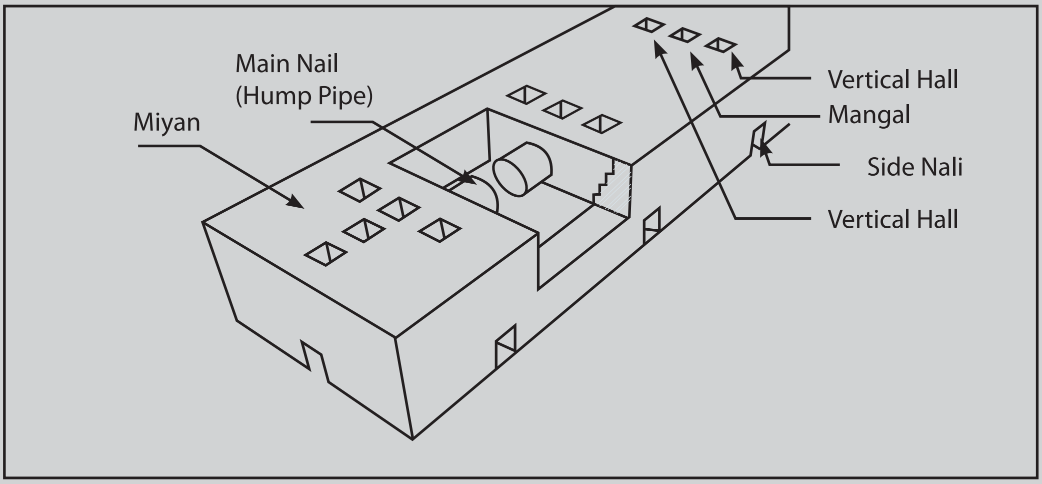


Fig 6 – Schematic diagram of flue duct system

The main nali is either circular or rectangular and runs throughout the length of Miyan, whereas the side nali is rectangular, constructed at regular spacing throughout the Miyan wall. The structures are connected by a tubular metal casing called a shunt. Vertical hall or Mangaal is a vertical rectangular structure that serves as the connector between the side and the main nail with a shunt.

Pressure loss or drop occurs when the frictional forces act on the flue gasses as it flows through the duct system. In a brick kiln duct, the pressure loss occurs mainly due to surface roughness, joints, duct convergence, duct divergence and bends. Pressure loss at different components has been calculated and also considered while designing the flue duct system. The pressure loss calculation and the detail design of flue duct components are presented in the section below.

7.1 Calculation of pressure loss in flue gas duct system

Pressure loss due to friction in ducts: The frictional loss is given by the below mentioned formula.

$$P\ loss = \lambda (L / dh) (\rho v2 / 2)$$

Where,

P loss	=	*pressure loss (Pa or N/m2)*
ρ	=	*density of the fluid (kg/m3)*
v	=	*flow velocity (m/s)*
λ	=	*friction coefficient*
L	=	*length of duct or pipe (m)*
dh	=	*hydraulic diameter (m)*

In above formula, to determine **the friction coefficient (λ)**, other parameters have to be determined. The detail steps to determine the friction coefficient are given below.

7.1.1 Determination of Reynold's Number

To calculate the frictional loss in any conduit, it is necessary to know the type of flow inside the duct, whether it is laminar, transient or turbulent. To determine the type of flow, the dimensionless number called Reynolds Number (Re) is used.

A flow is:

- *laminar if Re < 2300*
- *transient for 2300 < Re < 4000*
- *turbulent if Re > 4000*

Calculation of Reynold's Number, *Re,*

$$Re. = dh\ v\ \rho / \mu$$

Where,

Re	=	*Reynolds number*
v	=	*velocity, m/sec = 5 m/s*
ρ	=	*fluid density at given temperature, kg/m3 = 0.9461kg/m3*
µ	=	*dynamic or absolute viscosity, Pa s =1.983 x 10-5 (see Annex 1)*
dh	=	*hydraulic diameter, m= 1.02 m (40 inch circular RCC pipe)*

Therefore,

$$Re = 1.02 \times 5 \times 0.9461 / 1.983 \times 10^{-5} = 242,369.54$$

The flow is turbulent.

7.1.2 Calculation of roughness ratio

Roughness ratio is defined as the ratio of absolute roughness (K) and hydraulic diameter (dh).

K = 1 mm (Roughness value for ordinary concrete pipes, refer Annex 2)
Roughness ratio ***(K/dh) = 0.000984*** *(assuming roughness of ordinary concrete pipes)*

7.1.3 Calculation of frictional factor

The frictional factor (λ) can be determined from Moody's diagram for calculated value of Reynold's Number (Re) and Roughness ratio (K/dh), refer Annex 3.

The frictional factor $(\lambda) = 0.024$ *(for hume pipe)*

7.1.4 Pressure loss in duct due to friction

The frictional loss in a pipe when flowing through a certain length of pipe is calculated below.

$$P_{loss} = \lambda \,(L / dh)\, (\rho v^2 / 2)$$

Where,

P_{loss} = pressure loss (Pa (N/m²)	
ρ = density of the fluid (kg/m³)	= 0.9461 kg/m³
v = flow velocity (m/s)	= 5 m/s
λ = friction coefficient	= 0.024
L= length of duct or pipe (m)	= 78 ft =23.78 m (assuming Miyan length of 156 fts)
dh = hydraulic diameter (m)	= 1.02 m

Therefore,

P_{loss}	=	**6.64 N/m2**
	=	**6.64/ 9.81 mm of WG**
	=	**0.677 mm of WG**

7.1.5 Pressure loss due to bends in duct system

There are five bends in the flue inlet tunnel (nali) before the flue enters the chimney duct. The bend locations are as follows:

One horizontal bend just at the mouth of the side inlet (side nali)
One vertical bend inside side nali just before the flue entering the shunt
Two bends inside the shunt
One bend when the flue flows from the shunt to the main tunnel (main nali)

The pressure loss in bends is given by,

$$
\begin{aligned}
P\ loss &= \lambda\ (\ \rho\ v2\ /\ 2\ ) \\
&= 0.024 \text{ x } 0.9461 \text{ x } 5 \text{ x } 5/\ 2 \\
&= 0.2838 \text{ N/m2} \\
&= 0.0289 \text{ mm of WG} \\
\text{Pressure loss for 5 bends,} &= 5 \text{ x } 0.0289 \\
&= 0.1447 \text{ mm of WG}
\end{aligned}
$$

The calculation shows that the pressure loss is negligible hence has not been considered in further calculation. The pressure loss is mainly influenced by the length and number of bends in the duct system, which remains same for IDZZK and NDZZK.

7.2 Main nali

The main nail is designed with a circular hume pipe of 40 inch diameter. The circular hume pipe is proposed for faster reconstruction requirement in the post-earthquake context. In case of brick masonry construction, the main nail should be rectangular with equivalent dimensions.

In addition to the theoretical calculations, following considerations are also taken into account for the proposed dimension.

- The size is based on available sizes of circular pipes in the market
- The higher value is taken into account to address the deposition of soot in the duct

The detailed calculation process followed for proposing the flue system is as follows:

Calculations of flue inlet dimensions for IDZZK

For the given value of SEC, 1.1 MJ/ kg of fired brick

The coal consumption per brick	= *1.1x 2.1/ 22.99 kg*
	= *0.10048*
	= *100.48 grams*
Required coal quantity per day i.e. for 70,000 bricks	= *0.10048 x 70,000*
	= ***7033.49 kg***
Amount of air for coal burning	= *7033.6 x 8.52*
	= ***59,925.35 kg***
Excess air (EA) quantity	= *300% X 59,925.35 kg*
	= ***1797766.05 kg***

Total air including EA	= *59,925.35 +1797766.05*
	= ***239,701.4 kg***
Air density at temp 100oC	= *0.9461 kg/ m^3 (Refer Annex 4)*
Total air quantity in volume	= *239,701.4 /0.9461*
	= ***253, 3557.36 m^3***
For the worst case, increase 20%	= *1.2 x 253, 3557.36 m^3*
	= ***304, 028.83 m^3***
Moisture content in green bricks	= *7.5% x 70,000 x 2.25*
	= ***11,812.5 Kg***
Specific volume of moisture at 100oC	= *1.67 m^3/kg*
Volume of moisture	= *1.67 x 11,812.5 m^3*
	= ***19726.88 m^3***

Assuming twice of volume of air for initial firing, for worst case scenario,

The volume of moisture	= *2 x 19726.88 m^3*
	= ***39,453.75 m^3***
TOTAL AIR VOLUME (Q)	= *304, 028.83 + 39,453.75*
	= *343, 482.58 m^3 per day*
	= *343, 482.58/ 3600/24 m^3/sec*
	= ***3.98 m^3/ sec***

The Volume of fluid (Q) flowing with velocity (v) thorough a chimney with cross section area (a) can be calculated using following formula,

Q = *a x v*

Where,

Q = *Volume of gas flowing per second (m3/s) = 3.98 m3/ sec*
v = *Air flow rate i.e. velocity of gas (m/s) = 5 m/sec*
a = *Cross sectional area through which gas flows (m2) = ?*

Hence,

a	= *3.98/5*
	= *0.80 m2*
	= *8.5 ft2*

For Circular Section,

$$a = \pi D2/4$$
$$D = 3.30\ ft$$
$$= 39.62\ inch$$
$$\approx \mathbf{40\ inch}$$

Hence, the main duct is designed to be a circular pipe of 40 inch diameter.

Calculations of flue inlet dimensions for NDZZK

The diameter of the circular section for NDZZK was calculated following the same formulas and procedures. The calculated value of the circular section = 40.77 inch.

Hence, the main duct is designed to be a circular pipe of 40 inch diameter.

7.3 Side nali

Soot deposition is higher in the main nali compared to side nali. Hence, the area of side nali should always be smaller than the main nali. The cross section area of the side nail is maintained at70% of the main nali. The calculation of the side nali is shown below:

$$\text{Required area of flue inlet} = 70\%\ of\ 8.5\ ft2$$
$$= 5.95\ ft2$$
$$\text{Assume, inlet width} = 2.5\ ft$$
$$\text{Inlet height} = 2.38\ ft$$

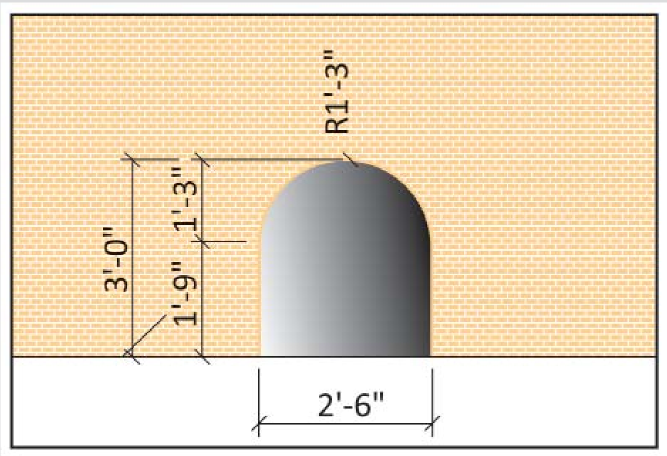


Fig 7 – Side nali details

Hence, the side nali is designed with a dimension of 2.5 ft x 1.75 ft rectangular + semi circular section with radius1.25 ft.

Check,

With the provided dimension, the area = 6.2 ft^2 *> 5.95* ft^2 ***OK***

7.4 Vertical hall /Mangaal

Vertical hall is a vertical rectangular structure that serves as connector between the side and main nali with a shunt. The opening size of vertical hall should be almost equal to the cross section of side nali and should be less than main nali.

Hence, in reference to above calculation of side nali, the cross-sectional area of the Vertical hall is ***2.5 ft x 2.5 ft***, which is ***6.25 ft2 .***

8 Kiln Wall Structure

The Outer wall and the Miyan wall are the two key kiln wall structures. The design of the kiln wall structure covers designing of these two key structures. The kiln wall structure is same for both induced draught and natural draught zig-zag kilns. The recent earthquake resulted in massive damage of wall sections in many brick kilns. The flow of workers is high around the walls; hence, the structural safely of wall should be given high priority. The structural safety analysis for the Outer and Miyan wall is done as in chapter 8.1. Similar, the heat loss from the Outer wall is substantial. The heat loss is caused due to air leakage in the kiln and by conduction through sidewalls. About 35 percent of the total heat is lost through kiln surfaces, of which 15 percent of the loss is from the top and the rest is from the sides and bottom. The analysis of heat loss and air leakages from the Outer wall are done and presented in the subsequent chapters. Hence, the wall design is **structurally safe, prevents air leakages and minimizes heat loss**.

8.1 Structural safety analysis theory

The wall is designed as a gravity wall. Horizontal and vertical seismic coefficient α_h and α_v are taken as per IS 1893(part 4): 2005 for seismic zone V.

The dynamic active earth pressure coefficient is calculated using ***Mononobe*** and ***Okabe (1992)***

$$(KA)_{dyn} = \frac{(1 \pm \alpha v)\cos 2(\phi - \alpha - \psi)}{(Cos\,\psi \cos^2 \alpha Cos(\delta + \alpha + \psi)} \times \left[\frac{1}{1 + \frac{(\sin(\phi + \delta)\sin(\phi - i - \psi)^2}{(\cos(\alpha - i)\cos(\delta + \alpha + \psi)^2}} \right]^2$$

Where, $\Psi = Tan\text{-}1\,[\alpha h / (1 \pm \alpha v)]$

Dynamic earth pressure,

$$PA = ½\, \delta\, (KA)_{dyn}\, H2$$

Where ,

α is the slope of the wall with the vertical

Φ is the angle of internal friction of soil

δ is the angle of wall friction

i is the inclination of backfill

γ is the unit weight of soil

Static active earth pressure coefficient is

Static active earth pressure coefficient is

$$(KA)_{stat} = \frac{\cos^2(\phi - \alpha)}{\cos^2 \alpha \cos(\alpha + \delta)} \left[\frac{1}{1 + \frac{(\sin(\phi + \delta)\sin(\phi - i)^{1/2}}{(\cos(\alpha - i)\cos(\delta + \alpha)^{1/2}}} \right]^2$$

1.5

Dynamic increment = PA(dyn) – PA(stat)

The state earth pressure will act at h/3 from the base and dynamic increment at h/2 where h is the height of the soil

For a safe design the wall must be safe against the following.

No sliding: The wall must be safe against sliding. The safety against sliding is calculated as follows.

$$\mathbf{Fs} = \frac{\mu R_v}{R_H} > 1.5$$

- Fs is the factor of safety against sliding μ is the coefficient of friction between the base of the wall and the soil $\mu = \tan\delta$
- R_V and R_H are vertical and horizontal components of the Resultant force R.

No overturning : The wall must be safe against overturning about the toe. The factor of safety against overturning is given by

$$F_o = \frac{\Sigma M_R}{\Sigma M_o}$$

- *Fo should be between 1.5 to 2.0*
- *ΣMR = sum of resisting moment about the toe*
- *ΣMo= sum of overturning moment about the toe*

No bearing capacity failure : The pressure caused by Rv at the toe of the wall must not exceed the allowable bearing capacity of the soil. The pressure distribution at the base is assumed to be linear. The maximum pressure is given by

$$Pmax = Rv/b(1+6e/b)$$

The factor of safety against bearing pressure is given by Fb = qna/Pmax>3

Where,

e is the eccentricity

b is the base width

qna is the allowable bearing pressure

8.2 Outer wall design

Little consideration is given in designing and constructing the kiln walls. Generally, the outer wall is a double wall constructed by joining two bricks from bottom to top in each row. The mud is then piled on the outer side of the wall. Based on the good practices, a cavity wall with insulation filling of mud/ ash in between is proposed. The two walls are connected with the connecting wall built at certain interval (refer fig 8).

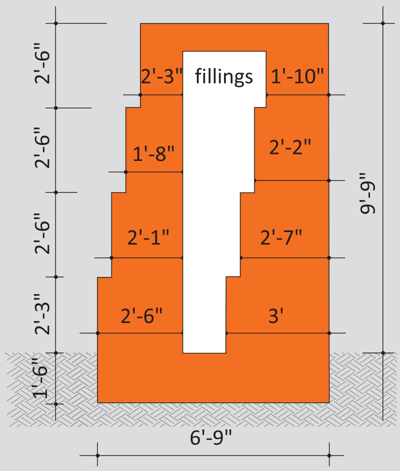


Fig 8 – Cross section of the outer wall

8.2.1 Structural analysis of the outer wall

The structural safety analysis of the proposed outer wall designed

Outer wall		
Unit weight of soil	= 19	kN/m^3
Unit weight of brick	= 17	kN/m^3
Unit weight of brick stack	= 7.1	kN/m^3
Surcharge slope(ε)	= 30	
	degree	***radian***
δ , Wall friction	= 20	= 0.35
Ø, Internal friction	= 33	= 0.58
α, Slope of wall	= 0.26	= 0.005
Ψ + ve	= 4.399	= 0.08
Ψ –ve	= 4.764	= 0.08
Soil Bearing Capacity	= ***100***	kN/m^2
Seismic coefficient		
Along H	= 0.08	
Along V	= 0.04	
Dynamic earth pressure coefficient		= 0.3095

Dynamic		Static
Positive	**Negative**	
0.887	0.819	0.752
0.348	0.354	

Dynamic earth pressure coefficient	= 0.309
Dynamic earth pressure coefficient -ve	= 0.285
Static active earth pressure coefficient	= 0.266
Take dynamic coefficient	**= 0.3095**

Height of wall	=	2.97	m
Embedment	=	0.45	m
No of Course	=	4	no
Width of Bed	=	2.06	M

Active Pressure(Pa)	=	20.00	kN
Dynamic earth pressure	=	23.20	kN
Dynamic increment	=	3.20	kN/m

	Load	Unit	Moment	Unit	
Horizontal component of P2stat	= P2statH	= **18.772**	kN/m	**18.60**	kNm
Vertical component of P2stat	= P2statV	= **6.894**	kN/m	**14.08**	kNm
Horizontal component of P2dyn	= P2dynH	= **3.004**	kN/m	**2.98**	kNm
Vertical component of P2dyn	= P2dynV	= **1.103**	kN/m	**2.25**	kNm

Course	Course Dimension		Offset	Mass		Moment about toe	
	width(m)	height(m)		Gabion	Soil	Soil	Gabion
6	0	0	1.55	0.0	0.00	0.00	0
5	1.55	0.762	0.10	20.1	1.30	2.07	15.565
4	1.65	0.762	0.11	21.4	2.85	4.86	17.638
3	1.76	0.762	0.29	22.8	11.11	21.14	20.068
2	2.046	0.686	0.00	23.9	0.00	0.00	24.402
1	2.046	0.457	0.00	15.9	0.00	0.00	16.268
				∑V=	**119.3**	**∑Mr=**	**122.01**

Overturning Stability

Overturning Moment	= 21.58		
Resisting Moment	= 138.34		
Factor of Safety on Overturning	= 6.4		***OK***

Sliding Stability

Friction Coefficient	= 0.45		
Sliding force	= 21.78		
Resisting force	= 127.3		
Factor of Safety on Sliding	= 2.63		***OK***

Bearing Stability

Eccentricity(e)=	= 0.105		***OK***
σ1	= 81.47	*kN/m²*	***OK***
σ2	= 42.97	*kN/m²*	***OK***

8.2.2 Heat loss from the outer wall

The temperature inside the kiln is higher, as compared to the ambient temperature and because of this, there is a heat loss from the kiln through the kiln wall. For the purpose of calculating heat loss, the length of the kiln wall is 196 ft (100 ft cooling zone + 36 ft firing zone + 60 ft pre-heating zone). The heat loss through the kiln wall will depend on the wall thickness. The thicker the wall, the less the heat loss through the walls. For a comparative analysis, heat loss through the walls has been calculated for two wall thickness values – 18 inch (1.5 ft), which is the usual practice and 5 ft, which is recommended to reduce the heat loss.

The temperature at the inner surface of the kiln wall is highest in the firing zone, and it decreases along the length of the kiln wall in both the directions i.e. towards cooling zone as well as towards pre-heating zone. For simplicity of calculations, the length of the kiln wall under consideration is divided into several parts and temperatures of inner as well as outer surfaces of each of the individual part is taken as uniform throughout the surface area of that part as shown below Fig 9:

	Cooling zone			Firing zone	Pre-heating zone	
Length of wall (ft)	30	35	35	36	30	30
	←100 ft→			←36 ft→	←60 ft→	
Temperature (inner kiln wall surface) T_1 ⁰C	150	300	500	800	200	60
Ambient temperature, T_2 ⁰C	30	30	30	30	30	30

The heat transfer takes place from inside the surface of the kiln wall to the outside surface of the kiln wall through conduction and from outside surface of the kiln wall to the ambient air through convection and radiation. To calculate the heat loss through the kiln walls, a steady state heat transfer condition is assumed. Now consider any individual part of the wall. Assume that the temperature of outside surface of the kiln wall is T.

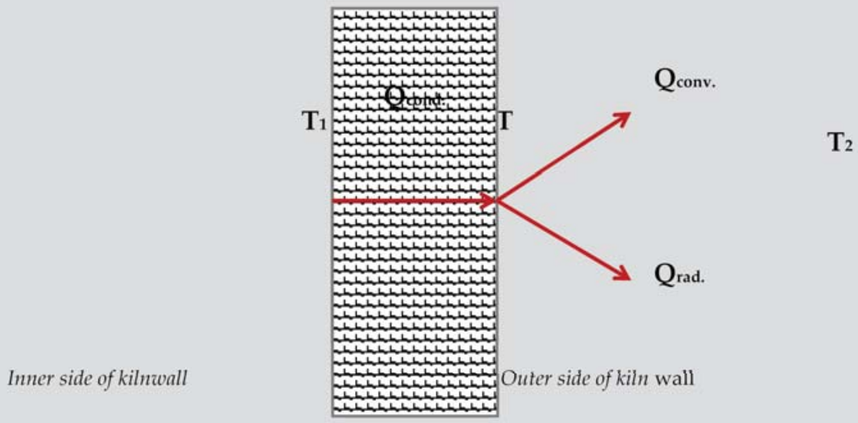


Fig 9 - Heat transfer in the kiln wall

The formulae for different modes of heat transfer will be

$$Q_{cond.} = \frac{k * A}{l} * (T_1 - T)$$

$$Q_{condv.} = h * A * (T_1 - T_2)$$

$$Q_{rad.} = \sigma * \varepsilon * A * (T^4 - T_2^4)$$

Where,

k = *thermal conductivity the kiln wall*[2] = 0.8 W/(m-K)

A = *surface area of individual part of the kiln wall*

= *height of kiln wall (10 ft) x length of part of the kiln wall*

l = *thickness of kiln wall = 18 inch (case 1: usual practice) and 5 ft (case 2: recommended)*

h = *convective heat transfer coefficient of outer surface of kiln wall* = 3 W/(m^2-K)

σ = *Stefan-Boltzmann's constant* = $5.67x10^{-8}$

ε = *emissivity of outer surface of kiln wall*[4] = 0.75

[2] http://www.engineeringtoolbox.com/thermal-conductivity-d_429.html

Now for steady state condition,

$$Q_{cond.} = Q_{conv.} + Q_{rad.}$$

Using this steady state condition, temperature of outside surface of the kiln wall, T, is calculated. Now the heat loss through any individual part of the kiln wall can be calculated as

$$Q = Q_{cond.} = \frac{k * A}{l} * (T_1 - T)$$

The total heat loss through the kiln wall will be the addition of heat losses through each part of the kiln wall.

The table below provides the results of the calculations done for determining heat loss through the kiln wall with the help of excel sheet which is enclosed for reference.

Table 3– Heat loss comparison through different outer wall designs

	18 inch wall thickness	5 ft wall thickness
Production capacity (bricks/day)	70,000	70,000
Total heat loss through the kiln wall (MJ/day)	7,533	2,508
Equivalent amount of coal (CV = 5500 kcal/kg) being wasted as heat loss from kiln wall (in kg/day)	327.7	109.1
% of total heat input	4.7 %	1.6%

Note : Heat loss comparison has been done for IDZZK only. For NDZZK it will be in the same proportion.

8.2.3 Air leakage into the kiln circuit through the outer walls

The air required for combustion of fuel in the kiln is desired to enter the kiln circuit from the brick unloading point and flow through the cooling zone, firing zone and pre-heating zone before it gets discharged into the atmosphere through the chimney. As the kiln operates at negative pressure (around 30 mm water column or even higher), there is a possibility of leakage of air inside the kiln through the kiln walls. Ideally, the leakage should be completely avoided as the infiltrated air may not be utilized in the combustion of fuel and heat recovery in the kiln.

[3] *Sameer Maithel (2003). Energy utilization in brick kilns.*
[4] *http://www.engineeringtoolbox.com/emissivity-coefficients-d_447.html*

The amount of air leakage inside the kiln through the kiln wall is given by

$$V=\alpha * A * \Delta P / t$$

Where,

V	=	*amount of air leakage in cubic feet per second*
α	=	*leakage coefficient = 1.25 (for brick wall made with mortar)*
A	=	*surface area of the wall in square feet= 196 * 10 = 1960 square feet*
ΔP	=	*mean pressure difference across the wall in inch of water column = 15/25.4 = 0.59 inch (Assuming maximum draught inside the kiln circuit = 30 mm water column, so mean draught inside the kiln = 15 mm water column)*
t	=	*thickness of the wall in inch = 18 inch (case 1: usual practice) and 5 ft (case 2: recommended)*

For a comparative analysis, air leakages through the walls have been calculated for two wall thickness values: 18 inch (1.5 ft), which is the usual practice and 5 ft which is recommended to reduce the leakage. The results of the calculations are provided in the table below:

Table 4 – Air leakage through the kiln wall

	5 ft wall thickness	18 inch wall thickness
Amount of air leakage (m3/day)	59,000	196,000
Amount of air leakage % of total gas flowinside kiln	17%	57 %

Note : Calculated for kiln draft of 30 mm water column. Air leakage comparison has been done for IDZZK only. For NDZZK it is expected to be less.

8.3 Miyana wall design

Only the structural safety analysis has been done for the Miyana wall design. The dimension of Miyana wall is designed as follows:

Height of wall (given from basic design parameter)	=	2.97	m
Embedment	=	0.45	m
No of course	=	4	nos
Width of bed	=	1.37	m

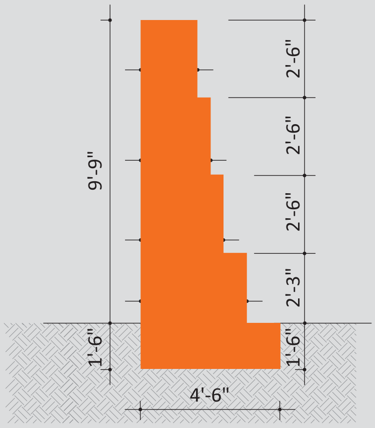


Fig 10 – Cross section of the Miyana wall

8.3.1 Structural analysis of the Miyana wall

The structural safety analysis of the designed Miyana wall (Fig 10) is done and confirmed as follows.

Unit weight of soil	= 19	kN/m^3
Unit weight of brick	= 17	kN/m^3
Unit weight of brick stack	= 7.1	kN/m^3
Surcharge slope(ε)	= 30	
	degree	***radian***
δ , Wall friction	= 20	0.35
Ø, Internal friction	= 33	0.58
α, Slope of wall	= 0.26	0.005
Ψ + ve	= 4.399	0.08
Ψ –ve	= 4.764	0.08
Soil Bearing Capacity	**= 100**	kN/m^2
Seismic coefficient		
Along H	= 0.08	
Along V	= 0.04	
Dynamic earth pressure coefficient	= 0.3095	

Dynamic		***Static***
Positive	***Negative***	
0.889	0.821	0.754
0.348	0.354	

Dynamic earth pressure coefficient	= 0.3095
Dynamic earth pressure coefficient -ve	= 0.2857
Static active earth pressure coefficient	= 0.2669
take dynamic coefficient	**= 0.3095**

Active Pressure(Pa)	=	22.41	kN
Dynamic earth pressure	=	25.98	kN
Dynamic increment	=	3.57	kN/m

	Load	Unit	Moment	Unit
Horizontal component of P2stat = P2statH	= 21.022	kN/m	= 20.83	kNm
Vertical component of P2stat = P2statV	= 7.761	kN/m	= 10.67	kNm
Horizontal component of P2dyn = P2dynH	= 3.352	kN/m	= 3.32	kNm
Vertical component of P2dyn = P2dynV	= 1.238	kN/m	= 1.70	kNm

Course	Course Dimension		Offset	Mass		Moment about toe	
	width(m)	height(m)		Gabion	Soil	Soil	Gabion
6	0	0	0.575	0.0	0.00	0.00	0
5	0.575	0.762	0.115	7.5	1.67	1.63	4.7124143
4	0.69	0.762	0.115	8.9	3.33	3.64	6.169
3	0.805	0.762	0.23	10.4	9.99	12.64	7.797
2	1.035	0.686	0.345	12.1	19.49	30.25	10.410
1	1.380	0.457	0	10.7	0.00	0.00	11.104
				∑V=	**84.1**	**∑Mr=**	**88.35**

Overturning Stability			
Overturning Moment	27.69	kNm	
Resisting Moment	100.72	kNm	
Factor of Safety on Overturning	3.6		OK
Sliding Stability			
Friction Coefficient	0.45		
Sliding force	26.75	kN	
Resisting force	93.1	kN	
Factor of Safety on Sliding	1.57		OK
Bearing Stability			
Eccentricity(e)=	-0.075		OK
$\sigma 1$	46.64	kN/m²	OK
$\sigma 2$	91.73	kN/m²	OK

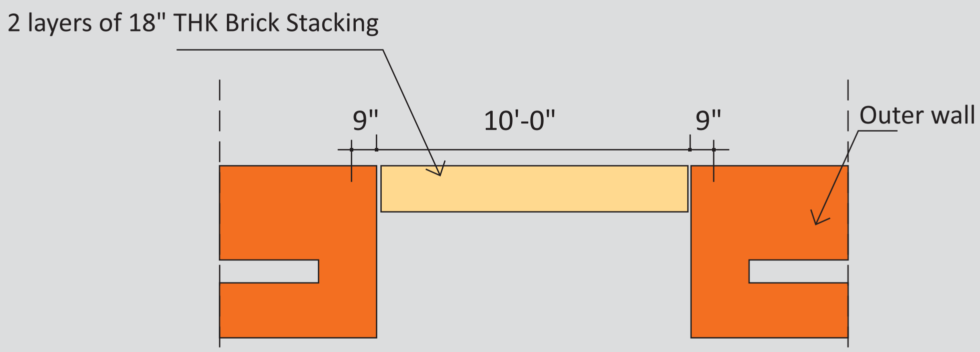
9 Wicket Gate/Dwari

Wicket gates are provided in the outer wall of the kiln for transportation of bricks in and out of the kiln. There is no consistent design methodology to define size, position and number of wicket gates (Dwari) in this type of kiln. The width of the wicket gates should be sufficient so that vehicles loaded with bricks can easily move in or out of the kiln. The wicket gates, which are in the kiln circuit, are required to be closed during firing. The general practice of defining the wicket gate in any kiln is based on the requirement of kiln owner. But there is less heat loss when there are smaller and fewer wicket gates. Hence, while designing the wicket gate, the following criteria should be considered:

- Minimum heat loss
- Easy transportation of green and fired bricks in or out of the kiln
- Easy and efficient access for green brick entry in the dug, depending upon the mode of transport, which is either human, animal, electric carts or trucks

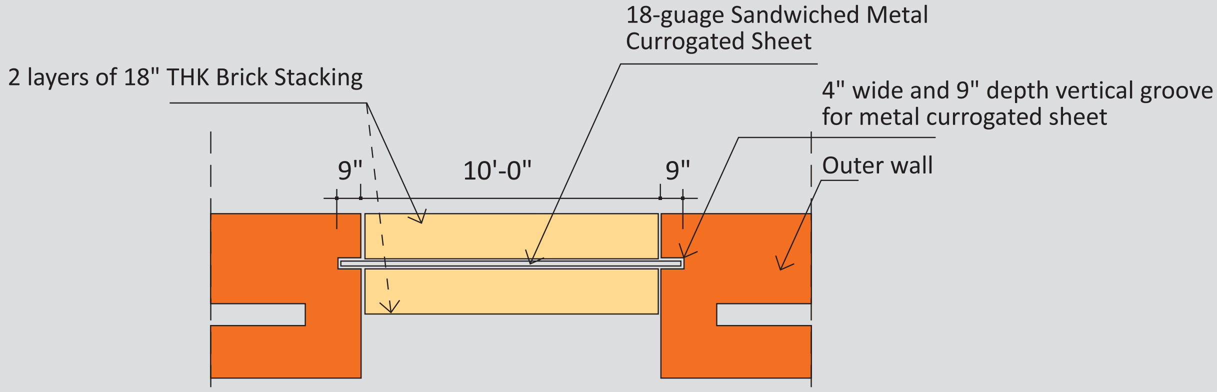
Based on transport and access criteria, a total 6 wicket gates (3 on either side) along the outer wall with 10 feet wide wicket gate is adopted in the design. No wicket gate has been proposed in the gali area. The design of wicket gate is same for both the IDDZK and NDZZK.

The common practice is to close the wicket gates with a two-brick (18 inch) thick wall with mud plaster. Heat loss and air leakage from the 18 inch wicket gate will be significant, especially when it is near to the firing zone. Some of the progressive kiln owners use improved practices in which the wicket gate consists of two layers of 18 inch brick wall, having a 4 inch gap filled with ash. Based on the feedback of these kiln owners, the 40 inch thick wicket gate can significantly reduce the heat loss and air leakage through the walls. Hence, the 40-inch design of the wicket gate is recommended. The comparative heat loss and air leakage analysis (as follows) of both the common and improved practices also confirms its effectiveness.



Common practice: *2 brick thick -18 inch wall*

Fig 11 – Wicket gate thickness



***Improved practice**: Two walls of 2 brick thick with ash insulation – 40 inch wall*

Fig 11 – Wicket gate thickness

9.1 Heat loss from wicket gate

Heat loss from the wicket gate has been calculated for two cases : i) the wicket gate is constructed as per common practice, i.e. 18 inch thick brick wall plastered with mud and ii) the wicket gate consists of two layers of 18 inch thick brick wall, having a 4 inch gap in between, which is filled with ash.

The values used for calculation of heat loss through the wicket gate are as below:

Width of the wicket gate, W = *10 ft*

Height of the wicket gate, H = *10 ft*

Area of the wicket gate, A = *100 square feet*

Temperature of inner surface of the wicket gate,

$T1$ = *800 0C (when wicket gate in the firing zone)*

Ambient temperature, $T2$ = *30 0C*

Thickness of wicket gate, l = *18 inch (case 1: usual practice) and 40 inch (case 2: recommended)*

k = *thermal conductivity the kiln wall = 0.8 W/(m-K)*

h = *convective heat transfer coefficient of outer surface of kiln wall = 3 W/(m2-K)*

σ = *Stefan-Boltzmann's constant = 5.67x10-8*

ε = *emissivity of outer surface of kiln wall = 0.75*

[5]*http://www.engineeringtoolbox.com/thermal-conductivity-d_429.html*
[6]*Energy utilization in brick kilns, Sameer Maithel*
[7]*http://www.engineeringtoolbox.com/emissivity-coefficients-d_447.html*

Assuming the steady state condition, heat loss through the wicket gate is calculated for both cases, and results are provided in the table below:

Table 5 – Comparative heat loss from different wicket gate designs

	18 inch wall thickness	40 inch thick wall
Production capacity (bricks/day) Total heat loss through the wicket gate in the	70,000	70,000
firing zone (MJ/day/wicket gate) Equivalent amount of coal (CV = 5500 kcal/kg)	930	450
being wasted as heat loss from kiln wall (in kg/day)	40.5	19.5
% of total heat input	0.58 %	0.28%

Note: Heat loss from wicket gate has been calculated for IDZZK. It will be in similar proportion in case of NDZZK.

9.2 Air leakage into the kiln circuit through the wicket gates

The amount of air leakage into the kiln is calculated, as it has been calculated for the kiln walls. The amount of air leakage inside the kiln through the kiln wall is given by

$$V = \alpha * A * \Delta P / t$$

Where,

V = *amount of air leakage in cubic feet per second*

α = *leakage coefficient = 2.5 (for a brick wall not made up of mortar)*

A = *surface area of the wicket gate in square feet = 10*10 = 100 square feet*

ΔP = *mean pressure difference across the wall in inch of water column = 15/25.4 = 0.59 inch (Assuming maximum draught inside the kiln circuit = 30 mm water column, so mean draught inside the kiln = 15 mm water column)*

t = *thickness of wicket gate in inch = 18 inch (case 1: usual practice) and 40 inch (case 2: recommended)*

Number of wicket gates in the kiln circuit = 3 to 4 (for calculation a factor of 3.5 has been taken)

The amounts of air leakage for both the cases are provided in the table below.

Table 5 – Comparative heat loss from different wicket gate designs

	18 inch wall thickness	40 inch thick wall
Amount of air leakage (m3/day) through 3-4 wicket gates	70,300	31,600
Amount of air leakage as % of total gas flow inside the kiln	20 %	9 %

Note: Air leakage from wicket gate has been calculated for IDZZK. It will be in slightly less in the case of NDZZK.

10 Kiln Floor

The ground below the kiln continuously exchanges the heat with the kiln. Most of the heat absorbed by the floor of the kiln is conducted to the ground below. The amount of heat loss depends upon the ground condition. The water table and moisture content in the ground has a largerole in ground heat loss. The ground heat loss is about 10 – 20% of total heat input. Hence, it is a serious component to be considered for the energy-efficiency of the kiln. The floor design will be same for IDZZK and NDZZK.

10.1 Heat loss from the kiln floor

Temperature variation with depth from the kiln floor level

The Table 7 below provides the temperature variation with depth in the ground.

Table 7– Temperature variation across the depth from the kiln floor

Depth from the kiln floor level (meter)	Maximum measured temperatures (^oC) [measured at a location having relatively high moisture content in the soil]*	Maximum estimated temperatures (^oC) [calculated for a location having relatively low moisture content in the soil]**
0 (kiln floor)	781	980
0.1	-	780
0.15 (end of brick soling)#	348	-
0.2	-	600
0.3	-	450
0.40	127	350
0.5	-	300
0.65	110	-
0.98	110	-
1.0	-	200
1.5	-	160
1.60	69	-
2.0	-	130
3.0	40	-

**The floor of this kiln was made of a 15 cm thick layer of brick soling.*

** This column provides the temperature variation with depth in the ground, based on the calculations assuming one-dimensional transient heat flow in the ground. The soil/ground properties assumed for the calculations are provided below, and these properties are assumed to be uniform with depth in the ground:

Thermal conductivity of soil = *0.52 W/m-K*

Density of soil = *2050* kg/m^3

Specific heat of the soil, = *1840 J/kg-K*

10.2 Recommended kiln floor design

The detailed design of the kiln floor has not been carried out. Based on best practices and practical results from kiln operation, a design has been proposed as shown in Fig 12. The proposed floor design recommends a layer of sand, aluminum sheet and brick soling layers.

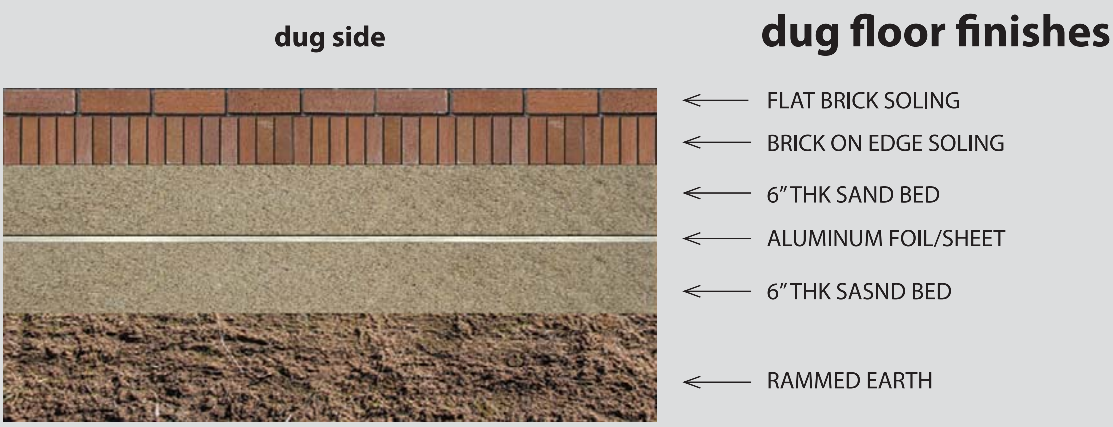


Fig 12 – Kiln floor design

11 Chimney

Chimneys were one of the hardest hit components of brick kilns by the recent earthquake. The chimney is the most important and costly section of a kiln structure. Hence, the chimney design is of prime concern for all kiln owners.

The quick damage assessment of a few brick kilns conducted after earthquake revealed the following:

- The chimney construction was done for bearing compressive loads only. The bending stress that occurred during the earthquake was not considered during chimney construction.
- Some of the chimneys were provided with horizontal bands, in regular intervals along the chimney height, but the vertical connections of horizontal bands were missing.

- There is no consistency with regard to chimneys size, such as chimney height, base width, foundation depth, inlet diameter, outlet diameter, etc. No chimney was constructed using an engineered design.
- Almost all of the chimney walls are made of brick and mud mortar. Only a few have surkhi (fired brick dust) and lime as mortar. Mud mortar has less capacity for handling shearing, such as occurred in the earthquake.
- The failure patterns of chimneys were different despite the fact that chimneys have similar sizes and were in close vicinity.
- Almost all chimneys have severe cracks, up to the base, which will require reconstruction or costly retrofitting.

The assessment shows that the chimney has to be carefully designed. At the same time, chimney reconstruction must be cheap, fast, easy and structurally safe. To address these requirements, two chimney options are analysed and designed. The following factors are considered in analysis and design of chimney:

- Chimney height
- Chimney shape and top-bottom area ratio
- Chimney structural design (foundation, beam, column, wall, etc.)

11.1 Chimney height

The government has imposed the regulation for chimney height considering the Maximum Limit for Suspended Particulate Matter (SPM) emission (refer Table 8). There is no consideration for SOx emission in the regulation.

Table 8– Current government standard for chimney height

Technology	SPM Maximum Limit(mg/Nm3)	Minimum Chimney Height (m)
IDZZK	600	17 m
NDZZK	700	30 m

Source: Environment Protection Regulation 1997

Chimney height has been calculated using an empirical formula recommended by the Central Pollution Control Board (CUPS/ 13/1984-85), India, which is based on the dispersion of sulphur dioxide (SO2) and particulate matter (PM) emissions.

The chimney height (H) in meters for the dispersion of sulphur dioxide is given by formula,

$$H = 14\ (Q)^{0.3}$$ *(Where Q is sulfulr emission rates in Kg/hr)*

Similarly, chimney height (H) in meters for dispersion of particulate matter (PM) is given by formula,

$$H = 74\ (Q)^{0.27}$$ *(Where Q is PM emission rates in tonne/hr)*

11.1.1 Chimney height for IDZZK

Based on SO_2 emission:

Fuel consumption	*= 293.0622*	*Kg/hr*
Sulphur content in fuel	*= 1.0%*	
Sulphur to SO_2 conversion	*= 90.0%*	
Sulphur consumption per hour	*= 2.6376*	*Kg/hr*
Q_{SO_2}	*= 5.2751*	*Kg/hr*

Note: Chimney height indicates height from the natural ground level

Hence, the chimney height based on SO_2 emission, H_{SO2} **= 23.06 m for IDDZK**

Based on PM emission:

Maximum allowable emission (National standard for Forced/Induced Draught)	*= 600*	*mg/m3*
	= 600 x 48887x1.5	*mg/day*
	= 1.8332625	*kg/hr*
Q_{PM}	*= 0.001833263*	*tons/hr*

The calculated chimney height based on PM emission, H_{PM} **= 13.5 m for IDDZK**

The calculation shows that chimney height required for dispersion of sulphur emissionis longer than that for particulate matter emission. However, sulphur content in fuel varies according to fuel type. Hence, the analysis with different fuel types and combination was done to calculate the required chimney height for sulphur dispersion. The result of the analysis for required chimney height is presented in the following table.

Table 9 – Chimney heights for sulphur dispersion against fuel type and combinations

Fuel combination	Coal	Biomass	Type of coal	Sulphur in coal (%)	Chimney height (m)
Option 1	100%	0%	Assam	1%	23
Option 2	80%	20%	Assam	1%	21.5
Option 3	80%	20%	Other Indian	0.5%	17.5
Option 4	80%	20%	Petcoke	3%	30

Taking in account opinions of kiln entrepreneurs, fuel combination option 3 is the most prevalent practice. Hence, based on the discussions with brick entrepreneurs in the technical meeting and taking into account the national standard, it was decided to **design the chimney for IDZZK with 17 m height from ground.**

11.1.2 Chimney height for NDZZK

Based on SO_2 emission:

Fuel consumption	= 209.3301	Kg/hr
Sulphur content in fuel	= 1.0%	
Sulphur to SO2 conversion	= 90.0%	
Sulphur consumption per hour	= 1.8840	Kg/hr
Q_{SO_2}	= 3.7679	Kg/hr

Hence, the chimney height based on SO_2 emission, ***HSO2 = 20.84 m for NDZZK***

Based on PM emission:

Maximum allowable emission		
(National standard for Natural Draught)	= 700	mg/m^3
	= 700 x 48887x1.5	mg/day
	= 2.13880625	kg/hr
Q_{PM}	= 0.0021388	tons/hr

The calculated chimney height based on PM emission, ***H_{PM} = 14.072 m for NDZZK***

The calculation shows that chimney height required for dispersion of sulphur emissionis again longer than that for particulate matter emission. However, for both SO_2 and PM dispersion cases, the required height is smaller for NDZZK compare to IDZZK.

Nevertheless, based on practical experiences, NDZZK requires the pressure difference of 8mm of water column for its effectiveness. Hence, the chimney height is recalculated to achieve a pressure difference of 8mm of water column.

The following formulas were use to determine the pressure difference in the chimney

$$\Delta P = Cah\left(\frac{1}{T_o} - \frac{1}{T_i}\right)$$

Where,

ΔP = available pressure difference, in Pa
C = Discharge Coefficient = 0.0342
a = atmospheric pressure, in Pa
h = height of the chimney, in m
To = absolute outside air temperature, in K
Ti = absolute average temperature of the flue gas, in K

The pressure difference has been calculated for different chimney height and atmospheric temperature. The result is shown below.

Outer Temperature (^oC)→ Height (m) ↓	0	5	10	15	20	25	30	35	40
25	8.56	7.99	7.43	6.90	6.38	5.88	5.40	4.93	4.48
26	8.90	8.31	7.73	7.17	6.64	6.12	5.62	5.13	4.66
27	9.25	8.63	8.03	7.45	6.89	6.35	5.83	5.33	4.84
28	9.59	8.95	8.33	7.73	7.15	6.59	6.05	5.52	5.02
29	9.93	9.27	8.62	8.00	7.40	6.82	6.26	5.72	5.20
30	10.27	9.59	8.92	8.28	7.66	7.06	6.48	5.92	5.38
31	10.62	9.90	9.22	8.55	7.91	7.29	6.70	6.12	5.56
32	10.96	10.22	9.51	8.83	8.17	7.53	6.91	6.31	5.74
33	11.30	10.54	9.81	9.11	8.42	7.77	7.13	6.51	5.91
34	11.64	10.86	10.11	9.38	8.68	8.00	7.34	6.71	6.09
35	11.99	11.18	10.41	9.66	8.93	8.24	7.56	6.91	6.27

Note: average temperature of the flue gas is assumed to be 100^{o}C and average outside air temperature is assumed to be 25oC.

Upon discussion with brick entrepreneurs and members of technical committee, the chimney height of 35m is selected for NDZZK. The pressure difference with this height was found to be 8.24mm of water column, which is higher than the desired pressure difference.

11.2 Chimney shape and top-bottom area ratio

The chimney shape and top-bottom area ratio has been determined using Computational Fluid Dynamics (CFD) analysis. The circular-shaped chimney is widely used, while there are few square-shaped chimneys in Nepal. The CFD analysis under the similar-input conditions resulted in similar level of discharge performance in both the chimney shapes at the height of 17 meter (refer Table 10). The practical experiences of kiln operators in India also reported that the square-shaped chimney performed better compared to circular shape. The square shape is easier to construct comparatively and given the present need for fast construction, the square-shaped chimney is proposed as 17 meter high for IDZZK. At the height of 35 m for NDZZK, the discharge performance of square shape is superior to the circular shape. However, the structural safety analysis resulted in the better performance of circular shaped chimney. Hence, the circular-shaped chimney is designed for NDZZK.

The CFD analysis of top-bottom area ratio has been done for both chimney shapes (refer to Table 10). The top-bottom area ratio is the ratio of inner cross-sectional area of chimney at the top and bottom. The analysis showed that discharge performance is superior at 1:5 top-bottom area ratio for both chimney shapes. Hence, for IDZZK design, top-bottom area ratio has been maintained at 1:5. However, for NDZZK design, top-bottom area ratio has been maintained at 1:9 considering the structural safety.

The CFD test output of various area-ratio in circular and square chimney is presented in the following table.

Table 10 - CFD test output for various area ratio in circular and square chimney

Area ratio*	Height (feet)	Inlet temperature (ºC)	Outlet temperature (ºC)	Roughness (mm)	Discharge of circular chimney (m^3/second)	Discharge of square chimney (m^3/second)
1:1	100	80	35	30	1.2047	1.8992
1:2	100	80	35	30	1.30365	1.90179
1:3	100	80	35	30	1.37742	1.91747
1:4	100	80	35	30	1.41359	1.90296
1:5	100	80	35	30	1.41623	1.90369
1:6	100	80	35	30	1.3986	1.88613

11.2.1 Determination of top-bottom area for IDZZK

The flue-gas velocity at one third chimney height is desired to be maintained at 3 m/s to ensure velocity detection during environmental monitoring. Taking this as a basic parameter, the top and bottom area of chimney has been calculated as follows.

Height of chimney	*17.00*	*m*
One third height of chimney	*5.67*	*m*
Velocity at one third height (desired velocity)	*3*	*m/s*
Flow rate of flue gases	*3.98*	*m3/s*
Cross-section area of chimney at one third height	*1.326*	*m2*
Cross-section area of chimney at one third height	*14.271*	*ft2*

Diameter for circular chimney	*4.263*	*ft*
Inner dimension for square chimney	*3.778*	*ft*
Ratio of bottom area to top area	*5*	*From CFD analysis*
X 0.481	*ft*	
Bottom diameter = D+2x	*5.225*	*ft*
Top diameter = D-4x	*2.337*	*ft*
Bottom cross-section area	*21.446*	*ft2*
Equivalent square dimension	*4.631*	
PROVIDE	***4.670***	
top cross-section area	*4.289*	*ft2*
Equivalent square dimension	*2.071*	
PROVIDE	***2.083***	
Bottom dimension (square)	*4.631*	
Top dimension (square)	*2.071*	
flue gas velocity at top	*9.981*	*m/s*
flue gas velocity at bottom	*1.996*	*m/s*

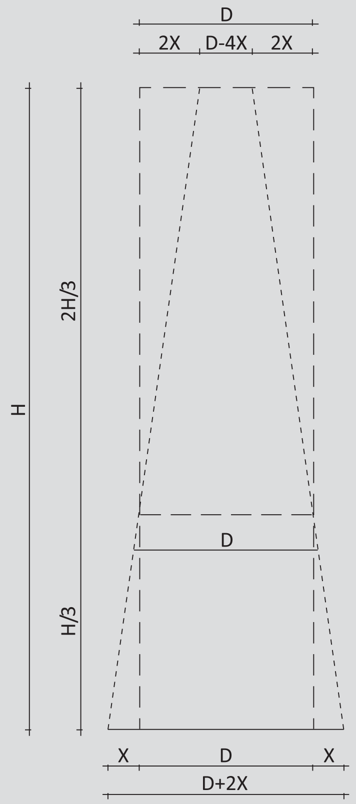


Fig 13 – Top-bottom area ratio diagram of IDZZK chimney

11.2.2 Determination of top-bottom area for NDZZK

The top bottom area for proposed NDZZK references one of the best performing natural draught zig-zag kiln in India. The top and bottom area of squared shaped NDZZK is

Top area = 9 sqft
Bottom area = 81 sqft

The proposed chimney in Nepal will have a circular cross section, so the equivalent top and bottom area for the circular chimney was calculated as

Top area = 9.6 sqft
Bottom area = 82.51 sqft

The area has been slightly modified to ease construction work.

11.3 Chimney structural design for IDZZK

The general practice for kiln design and construction in Nepal is based on conventional practices without considering the engineering requirement. Nepal lies in seismic zone V, which is the most severe for earthquakes. Nepal and Indian Standard Codes are followed for the structural design presented in this manual. Two types of chimneys have been designed for IDZZK considering the cost and construction time frame.

The seismic considerations are taken as recommended by IS 1893 Criteria for Earthquake Resistant Design of Structures: Part 1 General Provision and Buildings and IS 1893 Criteria for Earthquake Resistant Design of Structures: Part 4 Industrial Structures Including Stack-Like Structures. Two separate chimney modelswere analyzed in ETABs version 9.7 for time period as recommended by both the codes. The two models were then compared and the final design was done for the more conservative design values. The analysis presented in this manual is based on IS 1893, which was found to induce higher ranges of design values.

11.3.1 Design option 1– IDZZK: RC frame

Reinforced concrete columns at the four corners and reinforced concrete beams at vertical intervals are provided in design option 1. Masonry infill of brick in mud mortar is provided as infill in the reinforced concrete moment resisting frame chimney structure. Cladding for Reinforced Concrete members by bricks and mud is recommended to prevent corrosion of steel members from sulphur in the flue gas.

11.3.1.1 Basic structural design parameters for option 1 - IDDZK

Configuration parameters	
Height of the chimney from Ground Level(h′)	*17 m*
Internal dimension of chimney at the top	*0.686 m*
Internal dimension of chimney at the bottom	*1.54 m*
Thickness of masonry wall	*0.23 m*
Material parameters	
Concrete Grade	*20 MPa*
Steel Grade	*415 MPa*

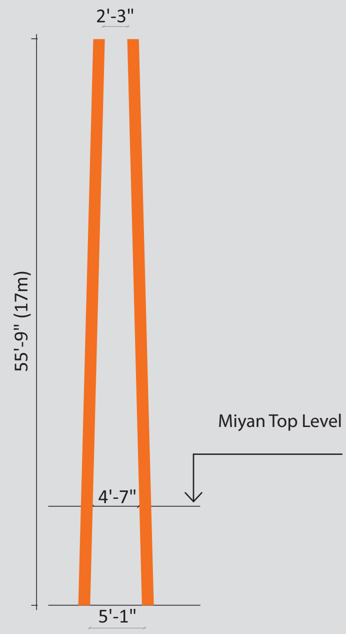


Fig 14 – Schematic diagram of chimney Option 1-IDZZK

11.3.1.2 Load calculations for ETABS

Dead load calculations:

Unit weight of masonry	*= 19kN/m3*
Height of masonry wall infill	*= 3m*
Height of masonry wall	*= 2m*
Thickness of masonry wall infill	*= 0.23m*
Uniform distributed load of the 3m high masonry wall infill in RC part of chimney in the intermediate beams w	*= 13.11kN/m*
Uniform distributed load of the 2m high masonry wall infill in RC part of chimney in the intermediate beams w	*= 8.74kN/m*
Taking w2	*= 9kN/m*

The reinforced concrete framed members are designed for earthquake loads

Wind load calculations:

Basic wind speed as per NBC 104: wind loads in taken as Vb	=	*47m/s*
Loads probability factor k1	=	*1*
Terrain height and structure size factor k2		
for height 17m category 2 and class A structures	=	*1.06*
for height 15m category 2 and class A structures	=	*1.05*
for height 12m category 2 and class A structures	=	*1.025*
for height 9m category 2 and class A structures	=	*0.99*
for height 6m category 2 and class A structures	=	*0.96*
for height 3m category 2 and class A structures	=	*0.93*

Topography factor k3 = 1:

Height above GL (m)	K1	K2	K3	Design Wind speed m/s	Design Wind press N/m2	Effective at the height	Width height for wind	Design wind load kN
17	1	1.06	1	49.82	1489.219	1.375	1	2.047677
15	1	1.05	1	49.35	1461.254	1.45	2.5	5.297044
12	1	1.025	1	48.175	1392.498	1.6	3	6.683992
9	1	0.99	1	46.53	1299.025	1.725	3	6.722452
6	1	0.96	1	45.12	1221.489	1.85	3	6.779262
3	1	0.93	1	43.71	1146.338	1.975	3	6.792055

11.3.1.3 Foundation design for option 1-IDDZK

The foundation was designed as a raft foundation as the bearing capacity assumed is low and all four columns are spaced closely. The design forces at the base of the chimney are calculated as the maximum reactions obtained from the ETABs model.

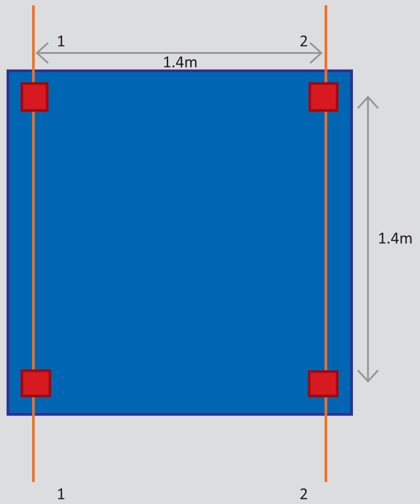


Fig 15 – Raft layout for chimney Option 1-IDZZK

Reinforcement calculation for foundation:

Taking bearing capacity of soil	= 100 kN/m2
Column size	= 350mm x 350mm
Reaction at each column	= 149kN
Factored reaction at each column	= 223.5kN
Distance between grid 1 and 2	= 1.75m
Projection from face of column	= 1000mm
Total length of the raft	= 4.1m
Total vertical column load	= 894Kn
Taking moment of column loads about the grid 1-1	
Centre of forces in x direction	= 0.375839m
Eccentricity in x direction ex	= 0.499161m
Since the structure and the loading is symmetrical in x and y direction	
Eccentricity in y direction ey	= 0.499161m
Moment of inertia in x direction	= 23.54801m4
Moment of inertia in y direction	= 23.54801m4
Area of raft	= 16.81m2
Since there is no eccentricity, there will be no moment in raft	
P/A	= 53.18263Kn/M2
Maximum moment in the raft due to the stress	= 20.35898kNm/m
The shear strength of raft will be governed by two way shear at the column	
Shear strength of concrete Tc'	= 1.118034N/mm2
For a column	
Effective depth of raft d	= 269.2955 mm

Adopt an effective depth = 410mm
Overall depth of raft = 450mm
Reinforcement is given by fyAst

$$M=0.87\left(d-\frac{fyAst}{fckb}\right)$$

From above, we get
Ast = 138.5032mm2/m
Minimum reinforcement in slabs = 0.12%
= 540mm2/m
Hence adopt Ast = 540mm2/m
Using 12mmdia bars
Spacing = 209.3333 mm

Provide 12mm dia bars at 150mm c/c both ways at top and bottom

Check for overturning:

The raft was checked for overturning for earthquake as well as wind forces.
Total weight of chimney from ETABs

W1	=	*580.46Kn*
Weight of raft W2	=	*189.1125kN*
Depth of raft from ground level	=	*1.65m*
Weight of soil on raft	=	*526.9935kN*

Fig 16 – Raft foundation for Option 1-IDZZK

Storey horizontal forces due to base shear:

Force ID	Storey	F(kN)	Storey height from bottom
GL	GL	0.67	1.65
F1	1FL	5.44	4.65
F2	2FL	13.64	7.65
F3	3FL	24.34	10.65
F4	4FL	36.54	13.65
F5	5FL	37.43	16.65
F6	6FL	12.54	18.65

Taking moment of the forces about toe O

ID	Force	Lever arm	Mo	Mr
W1	580.46	2.05		1189.943
W2	189.1125	2.05		387.6806
W3	526.9935	2.05		1080.337
GL	0.67	1.65	1.1055	
F1	5.44	4.65	25.296	
F2	13.64	7.65	104.346	
F3	24.34	10.65	259.221	
F4	36.54	13.65	498.771	
F5	37.43	16.65	623.2095	
F6	12.54	18.65	233.871	
		1745.82	**2657.96**	

Factory of safety against overturning = 1.522471 SAFE

Check for overturning due to wind loads:

Wind forces calculated for each storey

FORCE ID	Design Wind Load kN	Height from raft (m)
WL1	2.047677	18.65
WL2	5.297044	16.65
WL3	6.683992	13.65
WL4	6.722452	10.65
WL5	6.779262	7.65
WL6	6.792055	4.65

Taking moment of forces about Toe O

ID	Force	Lever arm	Mo	Mr
W1	580.46	2.05	0	1189.943
W2	189.1125	2.05	0	387.6806
W2	526.9935	2.05	0	1080.337
WL1	2.047677	18.65	38.18917	
WL2	5.297044	16.65	88.19578	
WL3	6.683992	13.65	91.23649	
WL4	6.722452	10.65	71.59411	
WL5	6.779262	7.65	51.86135	
WL6	6.792055	4.65	31.58306	
		372.66	**2657.96**	

Factor of safety against overturning = 7.132401 SAFE

Here we see that the wind loads are considerably less than earthquake loads
Hence, the columns and beams are designed for earthquake load

11.3.1.4 Column and beam design for option 1-IDDZK

The columns and beams were designed as per ETABs based on IS 1893 Earthquake Resistant Design of Structures Part 1 General Provisions and Buildings, and the detailing was done based on IS 13920 Ductile detailing code. However, shear reinforcement was designed manually using maximum shear values for the load combinations, as obtained by the ETABs analysis.

Design of longitudinal reinforcement of the column is as per ETABs:
Size of column = 350mm x 350mm

Level GL	Storey Ht.(m)	Long Reinforcement
1	1.65	8-25mm dia
2	3	8-25mm dia
3	3	8-25mm dia
4	3	4-25mm dia +4-20mmdia
5	3	4-25mm dia +4-20mmdia
6	3	8-20mm dia
7	2	8-20mm dia

Shear reinforcement calculations:

Shear reinforcement 10mm dia bars as per ductile detailing requirements

Size of beam	=	*230mm x 300mm*
Longitudinal reinforcement for all floors	=	*Top -2-20mm dia bars + 1-16mm dia bars*
	=	*Bottom -2-20mm dia bars +1-16mm dia bars*

Shear reinforcement design of beam 5

Shear force V	=	*154kN*
Bending moment M	=	*63kNm*
Overall depth of beam d	=	*273mm*
Width of beam b	=	*230mm*
Grade of concrete fck	=	*20N/mm2*
Grade of steel	=	*415 N/mm2*
No. of longitudinal bars provided	=	*420mm 216*
Ast	=	*1657-92mm*
Percentage of longitudinal steel p	=	*2.64042%*
Shear strength of concrete Tc	=	*0.82N/mm2*
Nominal shear stress Tc	=	*2.45262N/mm2*
Maximum shear stress Tc for M20 concrete	=	*2.8N/mm2*

Shear reinforcement needs to be provided

Shear strength reinforcement Vus	=	*102512.2 N*

Adopt 10 mm 2 legged stirrups

Area of steel of stirrups Asv	=	*157mm2*
Spacing of stirrups × is given by x	=	*150.9573mm*

Codes requires that X does not exceed 300mm

Or 204.75mm

Adopt x	=	*150.9573mm*
Rounding off x	=	*150mm*

Adopt spacing of stirrups of 150 mm c/c

11.3.2 Design option2 – IDDZK: Combination of RC frame and metal

The second option for chimney designed of reinforced concrete (RC) frame structure upto 6 meters, and metal chimney for 11 meters from the ground level.

The RC frame structure was analyzed as above in ETABs. The steel chimney was design based on literature from Design of Steel Structures by S. Ramamrutham and Design of Steel Structures by

I.C. Sayal and Satinder Singh. The chimney was designed to be self supporting on the RC beams. Riveted joints were designed as far as possible, due to ease of construction in the site. The weight and effect of the lining in the chimney was also taken into consideration in the design. The steel part was connected to the RC part with angles and base plate, held together by anchor bolts.

11.3.2.1 Basic structural design parameters for option 2- IDDZK

Configuration parameters

Height of the chimney from ground level(h')	*17 m*
Height of RC part	*6 m*
Height of metal part	*11 m*
Internal dimension of chimney at the top	*0.686 m*
Internal dimension of chimney at the bottom	*1.42 m*
Thickness of masonry wall	*0.23 m*

Material parameters

Concrete grade	*20 MPa*
Steel grade	*415 MPa*

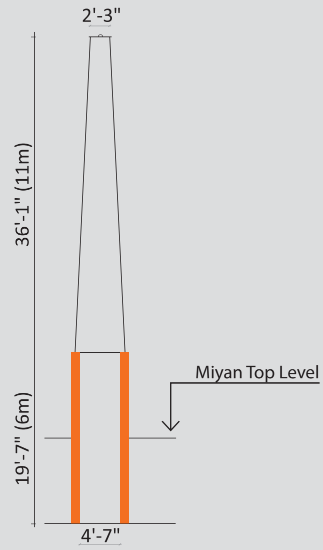


Fig 17 – Schematic diagram of chimney option 2-IDZZK

11.3.2.2 Load calculations for ETABS

Dead load calculations:

Unit weight of masonry	=	*19 kN/m3*
Unit weight of steel	=	*78.5 kN/m3*
Height of masonry wall infill	=	*3m*
Thickness of masonry wall infill	=	*2.23 m*
Height of metal part of chimney	=	*11.275 m*
Thickness of metal plate	=	*3mm*
Unit weight of the metal part of chimney on the top beam of the RC part w	=	*2.655263 kN/m Considering extra load due to connections and laps*
Taking w1	=	*5 kN/m*
Unit weight of the masonry wall infill in RC part of chimney in the intermediate beams w	=	*13.11 kN/m*
Taking w2	=	*13.5 kN/m*

Wind load calculations:

Basic wind speed as per NBC 104:		
Wind Loads is taken as Vb	=	*47 m/s*
The factors are taken from IS 875 part 3: Wind loads		
Probability factor k1	=	*1*
Terrain height and structure size factor k2	=	*1.06for category 2 and class A structures*
Topography factor k3	=	*1*
Design wind speed Vz	=	*49.82 m/s*
Design wind pressure Pz	=	*1489.219N/m2*

The reinforced concrete framed members are designed for earthquake loads.
The metal portion of the chimney is designed for wind loads.

11.3.2.3 Foundation design for option 2 - IDDZK

The foundation is designed as a raft foundation as for option 1.

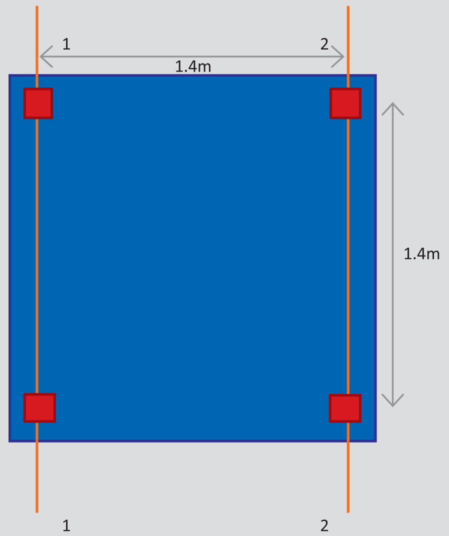


Fig 18 – Raft layout for option 2-IDZZK

Reinforcement calculation for foundation:

Taking bearing capacity of soil = 100kN/m2

Compressive strength of column fck = 20 N/mm2

Yield stress of steel fy = 415 N/mm2

Column size = 300mm x 300mm

Reaction at each column = 80 kN

Factored reaction at each column = 120 kN

Distance between grid 1 and 2 = 1.4 m

Projection from face of column = 550mm

Total length of the raft = 2.8 m

Total vertical column load = 480 kN

Taking moment of column loads about the grid 1-1

Center of forces in x direction = 0.7 m

Eccentricity in x direction ex = 0 m

Since the structure and the loading is symmetrical in x and y direction

Eccentricity in y direction ey = 0 m

Moment of inertia in x direction = 5.122133 m4

Moment of inertia in y direction = 5.122133 m4

Area of raft = 7.84 m2

Since there is no eccentricity, there will be no moment in the raft

P/A = 61.22449kN/m2

Maximum moment in the raft due to the stress = 15kNm/m

The shear strength of raft will be governed by a two way shear at the column

Shear strength of concrete Tc′ = 1.118034N/mm2

For a column

Effective depth of raft d = 223.2311mm

Adopt an effective depth = 410 mm

Overall depth of raft = 450 mm

Reinforcement is given by

M = 0.87fyAst (d-fyAst)/fck b

From above, we get

Ast = 101.8555mm2/m

Minimum reinforcement in slabs = 0.12%

Hence adopt Ast = 540 mm2/m

Using 12mm dia bars

Spacing = 209.3333mm

Provide 12mm dia bars at 150mm c/c both ways at top and bottom.

Check for overturning:

The raft was checked for overturning from earthquake as well as wind forces.
Total weight of chimney from ETABs
Total weight of the metal part as well as the RC part from ETABs

W1 = 305.96 kN
Weight of raft W2 = 88.2 kN
weight of soil on raft = 122.892kN

Fig 19 – Raft foundation for option 2-IDZZK

Storey horizontal forces due to base shear:

Force ID	F (kN)	Storey	Storey height from bottom
F1	1FL	2.34	1.65
F2	2FL	19.63	4.65
F3	3FL	48.87	7.65

Taking moment of the forces about toe O:

ID	Force	Lever arm	Mo	Mr
W1	305.96	1.4		428.344
W2	88.2	1.4		123.48
W3	122.892	1.4		172.0488
F1	2.34	1.65	3.861	
F2	19.63	4.65	91.2795	
F3	46.87	7.65	358.5555	
		453.696	**723.8728**	

Factor of safety against overturning = 1.595502 SAFE

11.3.2.4 Columns and beams design for option 2-IDDZK

The column and beams at the RC part was designed as option 1 - IDDZK.

Shear reinforcement calculations/design of beam of option 2:

Shear force V	=	*125kN*
Bending moment M	=	*64kNm*
Overall depth of beam D	=	*300mm*
Effective depth of beam d	=	*267mm*
Width of beam b	=	*230mm*
Grade of concrete fck	=	*20 N/mm2*
Grade of steel	=	*415 N/mm*
No. of longitudinal bars provided	=	*5 16 mm bars*
Ast	=	*1004.8 mm*
Percentage of longitudinal steel p	=	*1.636216%*
Shear strength of concrete Tc	=	*0.735N/mm2 IS 456:2000, Table 19*
Nominal shear stress Tc	=	*2.051783 N/mm2*
Maximum shear stress Tc for M20 concrete	=	*2.8 N/mm2 IS 456: 2000, Table 20*

Design of longitudinal reinforcement of the column is as per ETABs:

Size of column	=	*300mm x300mm*
Longitudinal reinforcement for all floors	=	*4-20mm dia + 4-16mm dia*
Shear reinforcement 8mm dia bars as per ductile detailing requirements		

Design of longitudinal reinforcement of the beam is as per ETABS:

Size of beam	=	*230mm x300mm*
Longitudinal reinforcement for all floors		
	=	*Top - 2-20mm dia bars + 1-16mm dia bars*
	=	*Bottom -2-20mm dia bars + 1-16mm dia bars*
Shear reinforce mentneed to be provided		
Shear strength of reinforcement Vus	=	*80863.65N*
Adopt 8mm 2 legged stirrups		
Area of steel of stirrups Asv	=	*100.48mm2*
Spacing of stirrups x is given by x	=	*119.7857mm*
Codes requires that x		

does not exceed 300mm or 200.25mm Adopt x	=	*119.7857mm*
Rounding off x	=	*150mm*

Provide 8 mm stirrups at spacing of 150 c/c

11.3.2.5 Metal part design of the chimney option 2- IDZZK

Design of metal part:

Size of chimney at base	=	*4 feet 2 inches = 1.25*
Equivalent diameter of chimney at base	=	*1.410832m*
Height of chimney	=	*11.275m*
Diameter of chimney	=	*1.410832 m*
		Equivalent diameter
Thickness of lining	=	*100 mm*
Thickness of the chimney plate required	=	*2.211872mm*
Adopt thickness of the chimney plate	=	*3 mm*
Consider 1mm length of the circumference		
Direct load due to wind action	=	*fw = 59.79726 N/mm*
Direct load due to self weight of chimney	=	*fs = 3.12543 N/mm*
Direct load due to weight of lining	=	*fL = 22.55 N/mm*
Maximum tensile load per mm length of the circumference	=	*fw-fs = 56.67183 N/mm*
Maximum compressive load per mm length of the circumference	=	*fw+fs+fL = 85.47269*
Maximum induced compressive stress	=	*28.49.9N/mm2*
Self compressive stress	=	*77.67505N/mm2*
Let diameter rivets be provided	=	*12mm*
Diameter of rivet hole	=	*13.5mm*
Since the wind effect is included, the safe stresses for rivets may be increased by 25%		
Permissible shear stress in rivets	=	*fs = 125N/mm2*
Permissible bearing stress fb	=	*375 N/mm2*
Rivet value in single shear	=	*17892.35 N*
Rivet value in bearing	=	*15187.5 N*
Let us provide a single riveted lap joint		
Number of rivets covered per pitch length	=	*1*
Pitch of rivets	=	*209.3341mm*
Generally the pitch shall not exceed 16 times the thickness		
of the plate i.e	=	*48mm*
Provide a pitch	=	*45mm*
Tearing strength per pitch length	=	*11340 N*
Actual pull per pitch length	=	*2550.232 N* ***SAFE***

Design of longitudinal reinforcement of the beam is as per ETABS:

Rivet value in double shear	*= 17892.35N*
Rivet value in bearing	*= 15187.5N*
Lesser rivet value	*= 15187.5N*
Consider one pitch length of the joint	
Number of rivets covered per pitch length	*= 1*
Shearing strength per pitch length	*= 17892.35 N*
Bearing strength per pitch length	*= 30375N*
Pitch of rivets	*= 355.3767mm*
Provide a pitch of 125 mm	
Tearing strength per pitch length	*= 40140 N*
Actual pull per pitch	*= 6800.62 N* ***SAFE***

Design of base plate:

Maximum pull per mm length of the circumference	*= 56.67183 N/mm*
Maximum compressive load per mm length of the circumference	*= 85.47269 N/mm*
Let diameter of bolts	*= 12mm*
Safe tensile stress in the bolt	*= 156.25 N/mm2*
Tensile strength of two bolts	*= 35342.92 N*
Spacing of bolts	*= 623.6417 mm*
Provide a spacing of 150mm	
Safe bearing strength of concrete	*= 5.3332 N/mm2*
Minimum width required for the base plate	*= 16.02653 mm*
But for accommodating the angles, let us provide a base plate of width	*= 230mm*
Cantilever projection of the base plate	*= 103.5mm*
Actual bearing pressure intensity	*= 0.37162 N/mm2*
Maximum blending moment for a 1mm wide strip of the base plate	*= 1990.445Nmm*
Permissible bending stress for the base plate	*= f = 246.6605 N/mm2*
Equating the moment of resistance to the maximum bending moment, we have	
Thickness of base plate t	*= 6.958265mm*
Adopt base plate of thickness	*= 10mm*

11.4 Chimney structural design for NDZZK

Natural draft is comparatively more slender and of greater height as compared to IDZZK. This is because the entire draught required for the flue gas outlet is created by the chimney itself. This draught is governed by the chimney configuration and height, hence the height of NDZZKs are generally greater than 30 meters. As per Nepal Government regulations, the minimum height of chimney is not less than 30 meters. Most of the international codes of practice and references pertaining to chimney design are based on circular configuration. Since NDZZks are slender and more susceptible to failure due to lateral loads, the configuration of the chimney is kept as circular for the design, and the chimney is designed as a shell structure.

11.4.1 Basic structural parameters for NDZZK chimney

Configuration parameters

Height of the chimney from ground level (h')	*35 m*
Internal dimension of chimney at the top	*1.067 m*
Internal dimension of chimney at the bottom	*2.948 m*
Thickness of RC wall	*0.2 m*

Material parameters

Concrete grade	*20 MPa*
Steel grade	*500 MPa*

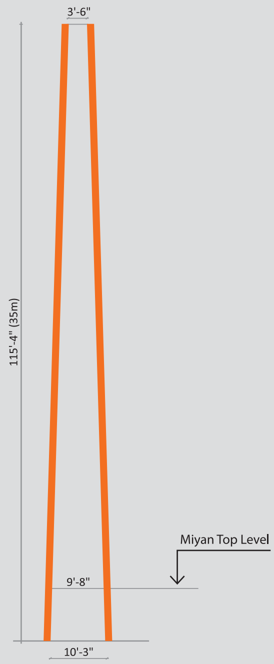


Fig 20 – Schematic diagram of NDZZK chimney

Design of longitudinal reinforcement of the beam is as per ETABS:

Permissible stress in steel Sst	*= 275 N/mm2*
Permissible stress in concrete in bending Scb	*= 7 N/mm2*
Unit weight of concrete	*= 25 kN/m3*
Modular ratio for M20	*= 13.33*
Thickness of fire brick lining	*= 100 mm*
Gap between fire brick lining and chimney	*=100 mm*
Unit weight of lining	*= 19 kN/m3*
Thickness of fire brick lining	*= 150 mm*
Temperature difference between inside and outside of the chimney	*= 75 degrees*
Bearing capacity of soil	*= 100 kN/m2*

11.4.2 Load calculations for NDZZK chimney

Calculation of earthquake loads for NDZZK chimney:

As per IS 1893 Part 4; Section 2, Table 5

The RC chimney is taken as Category 2 structure for industrial structures

Radius of gyration of the chimney at base	*= 2.46 m*
Slenderness ratio of the chimney	*= 14.22764*

As per IS 1893 Part 4; Table 6

Coefficient of time period depending upon the slenderness ratio of the structure CT	*= 28.30244*
Total weight of the structure including weight of lining is	*= 1138.042kN*
Height of the structure above base	*= 35m*
Modulus of elasticity of concrete	*= 21120000kN/m2*

As per IS 1893 Part 4; clause 14.1

Fundamental time period for stack like structures is T	*= 0.315805sec*
Importance factor for RC chimneys I	*= 1.5*
Reduction factor for RC chimneys R	*= 3*

As per IS 1893 Part 1

Zone factor Z	*= 0.36 for zone V*
Spectral acceleration coefficient for soft soil Sa/g	*= 2.5*
Design horizontal seismic coefficient Ah	*= 0.225*
Coefficient of shear force depending upon the slenderness ratio of the structure Cv	*= 1.179187*
Base shear for the building Vb	*= 301.942kN*
Height of center of gravity of chimney above base	*= 15.95m*
Distribution factor for moment Dm	*= 1at base*
Bending moment at base M	*= 4084.148 kNm*

Permissible Stresses

Total lateral earthquake load above base	*= 301.942kN*
Weight of ring beam to support lining and plaster	*= 362.8422kN*
Total dead load above base W	*= 1828.882kN*
Bending moment at base due to earthquake loads, M	*= 4084.148kNm*
Eccentricity e	*= 2.233139m*

Reinforcement

Providing reinforcements of 1% of the cross sectional area

Ast	*= 15448.8 mm2*
Using	*= 25 mm dia bars*
Number of bars	*= 31.488*
Provide	*= 50 bars of25 mm*

diameter

Equivalent thickness of steel ring is given by

ts	*= 3.175813 mm*
Analysis of stresses at base section	

a = angle subtended by the neutral axis at the centre,

the eccentricity is written as e	*= 2233.139 mm*
R	*= 1230 mm*
ts	*= 3.175813mm*
tc	*= 200mm*
alpha	*= 111 degrees*
a	*= 1.937315 radians*
e	*= 2230.894mm*
Hence take alpha	*= 111degrees*
	= 1.937315radians

Equating the sum of tension and compression forces to external load W

Stress in concrete Sc	*= 9.326665 N/mm2*
Stress in steel Ss	*= 263.2012 N/mm2*

The stress in steel and concrete are within permissible limits

Design of hoop reinforcement

Shear at the base of chimney	*= 301.942 kN*
Mean diameter at base	*= 2460 mm*

Provide = 10 mm dia. hoops at 200 mm c/c

Stress in steel Ss	*= 195.3478 N/mm2*

Stress is within permissible limit

Wind load calculations:

Height above GL (m)	K1	K2	K3	Design Wind speed m/s	Design Wind press N/m2	Effective at the height	Width height for wind	Design wind load kN
35	1	1.132	1	53.2275	1699.9	1.45	2.5	6.162138
30	1	1.12	1	52.64	1662.582	1.45	2.5	6.026859
25	1	1.095	1	51.465	1589.188	1.45	2.5	5.760806
20	1	1.07	1	50.29	1517.45	1.6	3	7.283762
15	1	1.05	1	49.35	1461.254	1.725	3	7.561987
10	1	1	1	47	1325.4	1.85	3	7.35597
5	1	0.5	1	23.5	331.35	1.975	3	1.963249

Adopt the highest wind intensity= 1.7 kN/m2

11.4.3 Chimney wall design

Permissible stresses

Weight of chimney	*= 2016.665 kN*
Weight of fire brick lining	*= 745.4517 kN*
Total wind load above base	*= 127.2408 kN*
The wind load is acting at a height of	*= 17.5m above base*
Total dead load above base W	*= 2762.117 kN*
Bending moment at base due to wind load M	*= 2226.713 kNm*
Eccentricity e	*= 0.806162 m*

Reinforcement

Providing reinforcements of 1% of the cross sectional area

Ast	*= 24303.6mm2*
Using	*= 25mm dia bars*
Number of bars	*= 49.5*

Provide 50 bars of 25mm diameter

Equivalent thickness of steel ring is given byts	*= 1.602067M*

Analysis of stresses at base section

a= angle subtended by the neutral axis at the centre,

the eccentricity is written as e	*= 806.1619mm*
R	*= 1935mm*
Ts	*= 1.602067mm*
Tc	*= 200mm*
Alpha	*= 322 degrees centigrade*
A	*= 5.61996 radians*
E	*= 1022.801mm*
Hence take alpha	*= 322 degrees*
	= 5.61996 radians

Equating the sum of tension and compression force to external load W

Stress in concrete Sc	*= -2.79401 N/mm2*
Stress in steel Ss	*= -4.41572 N/mm2*

The stress in steel and concrete are within permissible limits

Analysis of stresses at base section

Shear at the base of chimney	*= 127.2408 kN*
Mean diameter at base	*= 3870 mm*
Using	*= 8mm dia. Hoops at 200 mm c/c*
Stress in steel Ss	*= 81.76274 N/mm2*

Stress is within permissible limit

Temperature stresses (combined effect of wind loads, self weight and temperature)

Compression zone (leeward side)

Providing an effective cover of 50 mm to steel

Tc	*= 200mm*
Ts	*= 1.602067 mm*
Atc	*= 150*
A	*= 0.75*
P	*= 0.00801*
t	*= 75 degree Celsius*
Alpha	*= 0.000011 per degree Celsius*
M	*= 13.33*
Es	*= 210000 N/mm2*
Ec	*= 15753.94 N/mm2*
Sc	*= 2.794005 N/mm2*
By trial and error K'	*= 0.6995*
9.0546	*= 9.032914*

Value fo K' is okay

The stress in concrete Sc'	*= 10.08047 permissible*
Stress in steel Ss	*= -4.4352N/mm2*

(c) Stresses at neutral axis

K	*= 0.30743*
Stress in concrete Sct	*= 3.995669N/mm2*
Stress in steel Sst	*= 76.67524N/mm2*

Stresses are within permissible limits

Stresses in hoop steel due to temperature

Hoop steel of 8mm diameters provided at 200 mm c/c at base section

P	*= 0.001257*
A	*= 0.75*
M	*= 13.33*
K'	*= 0.142645*
Ss'	*= 56.75661 Sc'*
Sc'	*= 1.853956N/mm2*
Ss'	*= 105.2243N/mm2*

Total stress in hoop steel = stress due to shear + stress due to temperature difference = 186.987 N/mm2 Permissible

11.4.4 Foundation design of NDZZK chimney

Total vertical load on the base = 1692.9 kN
Bending moment = 1654.546 KNM
Allowable bearing pressure of soil = 100KN
Self weight of footing (assuming 10% of total weight) = 169.29 KN
Total load on soil = 1862.19 KN
D = diameter of circular footing for no t ension to develop W/A M/Z
D = 7.107961m = 7.2 m
Intensity of soil pressure (w) = 45.73714 KN/m2
2a = 7.2 2b = 2.46
Maximum bending moment if governed by the radial moment
Mr = bending moment at centre of the footing = 113.4458 KNm
Mr (max)= moment at junction of footing and chimney walls at a radius of 1.23m = 126.42 kNm
Concrete grade fck = 20/N/mm2
Steel grade fy = 415N/mm2
Effective depth = 375.4151mm
Adopt d = 400mm
Overall depth h = 450mm
Ast = 1521.739mm2
Provide 16mm bars at a spacing of 132.1264mm c/c
Provide 16 mm bars at spacing of 125mm c/c both ways and top and bottom of footing
The raft was checked for overturning for the earthquake as well as wind forces.
Total weight of chimney including soil
W1 = 1862.19
Weight of raft from ground level = 1.65m
Depth of raft from ground level = 1.65m

Check for overturning due to wind loads:

Wind load= 94.5455 kN

Height =19.15 m

Taking moment of the forces about toe O:

ID	Force	Lever arm	Mo	Mr
W1	1862.19	3.6		6703.882
W2	199.26	3.6		717.336
W3	94.5455	19.15	1810.56	
		1	**810.56**	**7421.218**

Factory of safety against overturning = 4.098883 SAFE

12 Fan

A fan is used for pumping and/or circulating the air through the duct system. The centrifugal fan is the fluid machinery used in duct air circulation or pumping system. The centrifugal fans have simple impeller construction, with a backward curved or forward blade. There are three types of centrifugal fans, (fig below), (i) backward curved impeller, (ii) forward curved impeller and (iii) radial impeller.

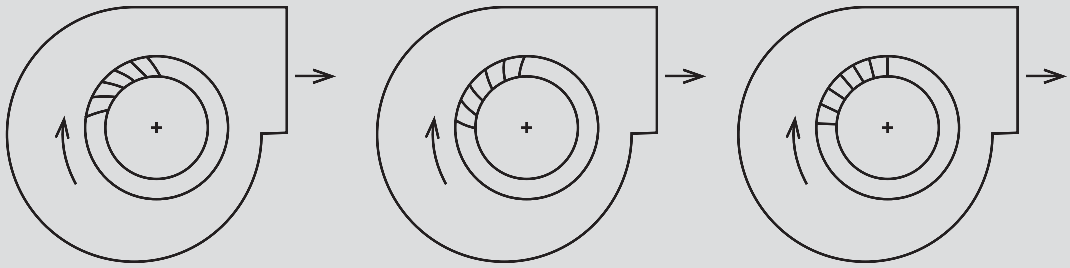


Fig (1) Centrifugal fan

For lower pressures and lower flow rates, the backward curved centrifugal fan is the most efficient option. It has higher efficiencies than the forward type. So the backward curved fan has been designed in this manual.

The backward curved blades must be operated at a much higher speed of rotation than the forward curved blades. In order to increase the flow rate and static pressure of the centrifugal impeller, it is necessary to change the parameters such as shape of a fan, by changing a shape of blade, pitching angle, tip clearance, blade chord angle, number of blades.

12.1 Impeller design

The designed dimension of the impeller is calculated for the optimum output using the iteration methodology.

12.1.1 Impeller eye and inlet duct size

Inlet duct size is 10 percent higher than the impeller eye size or impeller inlet diameter. This will make the conical insertion of the inlet duct and flow acceleration at impeller eye or inlet.

$$D_{duct} = 1.1 D_{eye} = 1.1 D_1$$

Assuming no loss during 90º turning from eye inlet to impeller inlet, the eye inlet velocity vector will remain the same as the absolute velocity vector at the entry of impeller.

$$i.e.\ V_{eye} = V_1 = V_{m1}$$

$$U_1 = 1.1V_2 = 1.1V_{m1}$$

Discharge $$Q = \frac{\pi}{4} D_{eye}^2 \times V_1$$

$$V_1 = \frac{4Q}{\pi \times D_1^2}$$

$$U_1 = \frac{\pi D_1 N}{60} = 1.1V_1$$

$$\therefore \frac{\pi D_1 N}{60} = 1.1 \frac{4Q}{\pi D_1^2}$$

12.1.2 Blade design

The blade profile is made by a tangent arc method. When this method is used, the impeller is divided into a number of assumed concentric rings, not necessarily equally-spaced between the inner and outer radii. The radius Rb of the arc is defining the blade shape between the inner and outer radii.

$$R_b = \frac{r_2^2 - r_1^2}{2[r_1 \cos\beta_1 - r_2 \cos\beta_2]}$$

12.2 Backward curved centrifugal fan design

12.2.1 Outer dimension of fan

Table 11 – Outer dimensions of fan

Maximum length	1.67 m
Maximum breadth	1.1 m
Maximum height	1.55 m

12.2.2 Design parameters for fan

Overall mass	=	*788 Kg (approximate with MS)*
Material volume	=	*101088304.45 cubic millimeters*
Impeller diameter	=	*1.15 m*
Suction diameter	=	*0.65 m*
Speed	=	*495 rpm*
Impeller tip velocity	=	*59.58 m/s*
Width of impeller	=	*0.39 m*
Discharge, Q	=	*5.06 m3/s*
Ideal shaft power	=	*1144 watt*
Efficiency of impeller	=	*81.44%*
Pressure difference	=	*436 Pascal*

Note : Overall electromechanical power has to be calculated

13 Annexes

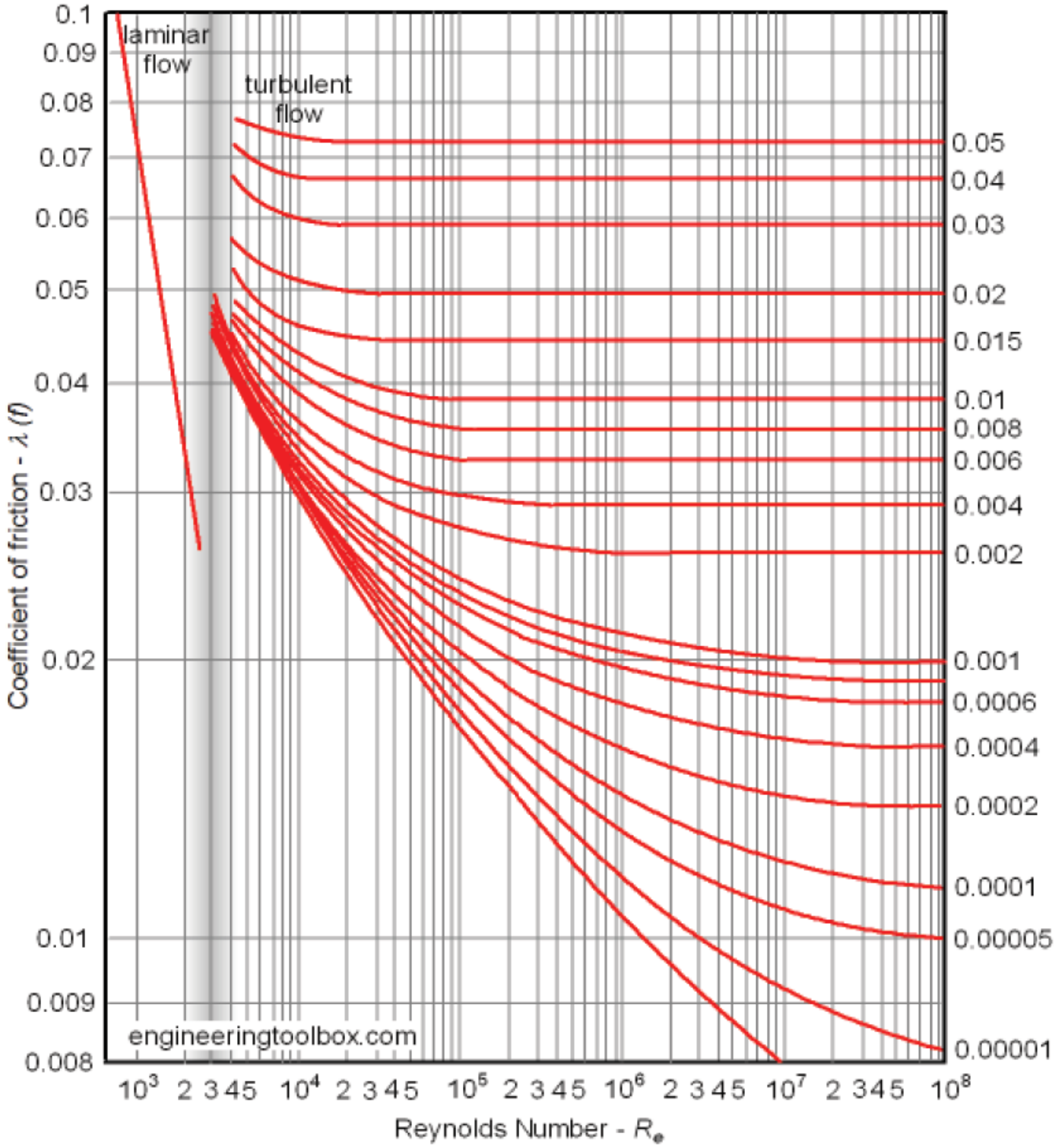
13.1 Annex 1 – Absolute viscosity

Liquid	Absolute Viscosity *) (Pa s)
Air	1.983×10^{-5}
Water	1×10^{-3}
Olive Oil	1×10^{-1}
Glycerol	1×10^{3}
Liquid Honey	1×10^{1}
Golden Syrup	1×10^{2}
Glass	1×10^{40}

13.2 Annex 2 - Absolute roughness

Surface	Absolute Roughness - k	
	10^{-3} (m)	(feet)
Copper, Lead, Brass, Aluminum (new)	0.001 - 0.002	$3.3 - 6.7\ 10^{-6}$
PVC and Plastic Pipes	0.0015 - 0.007	$0.5 - 2.33\ 10^{-5}$
Epoxy, Vinyl Ester and Isophthalic pipe	0.005	$1.7\ 10^{-5}$
Stainless steel	0.015	$5\ 10^{-5}$
Steel commercial pipe	0.045 - 0.09	$1.5 - 3\ 10^{-4}$
Stretched steel	0.015	$5\ 10^{-5}$
Weld steel	0.045	$1.5\ 10^{-4}$
Galvanized steel	0.15	$5\ 10^{-4}$
Rusted steel (corrosion)	0.15 - 4	$5 - 133\ 10^{-4}$
New cast iron	0.25 - 0.8	$8 - 27\ 10^{-4}$
Worn cast iron	0.8 - 1.5	$2.7 - 5\ 10^{-3}$
Rusty cast iron	1.5 - 2.5	$5 - 8.3\ 10^{-3}$
Sheet or asphalted cast iron	0.01 - 0.015	$3.33 - 5\ 10^{-5}$
Smoothed cement	0.3	$1\ 10^{-3}$
Ordinary concrete	0.3 - 1	$1 - 3.33\ 10^{-3}$
Coarse concrete	0.3 - 5	$1 - 16.7\ 10^{-3}$
Well planed wood	0.18 - 0.9	$6 - 30\ 10^{-4}$
Ordinary wood	5	$16.7\ 10^{-3}$
Brick wall/pipe	1.524-9.144	

13.3 Annex 3 – Moody's diagram



Moody's Diagram

13.4 Annex 4–Air density at various temperatures

Density and specific weight of air at temperatures ranging -40 - 1000 ºC (-40 - 1500 oF) at standard atmospheric pressure - Imperial and SI Units

Temperature	Density	Specific Weight
- t -	- ρ -	- γ -
(ºC)	(kg/m3)	(N/m3)
-40	1.514	14.85
-20	1.395	13.68
0	1.293	12.67
5	1.269	12.45
10	1.247	12.23
15	1.225	12.01
20	1.204	11.81
25	1.184	11.61
30	1.165	11.43
40	1.127	11.05
50	1.109	10.88
60	1.06	10.4
70	1.029	10.09
80	0.9996	9.803
90	0.9721	9.533
100	0.9461	9.278
200	0.7461	7.317
300	0.6159	6.04
400	0.5243	5.142
500	0.4565	4.477
1000	0.2772	2.719

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