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From the Editor

Once again we welcome our readers to the latest SCITECH journal, now in its Vol. 11 No. 1 edition. It has been a pleasure Compiling articles gathered over the past months from the different authors engaged in different fields.

As has been said many times before our profoundest thanks go to those who have contributed their articles for enhancing the readability of this journal. We would also like to extend our thanks to them, who are directly or indirectly involved in preparing this journal.

Views and suggestions from readers of the journal would be highly appreciated. We will bring out our forthcoming editions with all your comments incorporated.

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A BRIEF OVERVIEW OF MIMO WIRELESS COMMUNICATION AS A SIGNIFICANT TECHNICAL BREAKTHROUGH IN MODERN COMMUNICATIONS

Madhup Khatiwada*

Abstract

This paper presents an overview of Multiple-Input Multiple-Output (MIMO) system which is an emerging technique used in wireless communication. Firstly, we will present some background research leading to the discovery of the enormous potential of MIMO. We will then present the principles of MIMO along with the theoretic capacity, which will depict MIMO as an extraordinary bandwidth-efficient approach to wireless communication. Finally, we will discuss some of the spatial multiplexing detection techniques with some Monte-Carlo simulations to show the performance of these detection techniques for different antenna configuration.

Introduction

In recent years, one of the growing sectors of the communications industry has been wireless communication providing high-speed and better quality information exchange between mobile devices. Some of the major applications of wireless communications include internet-based mobile communications, video-conferencing, distance learning, wireless home appliances etc [1]. However, supporting these applications using wireless techniques poses a significant technical challenge.

From a technical point of view, the vital challenge faced in wireless communications lies in the physical properties of wireless channels. These physical properties can be described in terms of several distinct phenomena, including ambient noise, propagation losses, multipath and interference [2]. In addition to all these challenges, there is an increasing demand for higher data rates, better quality service, and higher network capacity. To meet these needs there is a requirement for new techniques that improve the spectral efficiency and increase the reliability of system.

Multiple-Input Multiple-Output (MIMO) technology promises a cost-effective way to provide these capabilities. A MIMO system comprises a wireless communication

* Department of Electrical and Electronics Engineering, Kathmandu University, Email: madhupk@nec.edu.np

link with multiple antenna elements in both transmitter and receiver. MIMO takes advantage of the multipath scenario by sending a single transmission from the transmitter antenna array to bounce along multiple paths to a receiver. Transmitting data on multiple signal paths increases the amount of information transferred in a system. [3]. Thus the system is able to handle more information and at a faster rate than a single-input single-output (SISO) scenario with a single path.

MIMO was conceived in the early 1970s by the researchers at Bell Laboratories while they were trying to address the bandwidth limitations that signal interference caused in large, high-capacity cables [4]. However it was not thought to be practical in that era because of the high expense incurred in generating the processing power necessary to handle MIMO signals. Later, with the advancement of technology and cost reductions in signal-processing schemes and with the need to meet the increasing demands, the researchers were compelled to reconsider MIMO for wireless systems [3].

Multiple-input multiple-output (MIMO) architecture has emerged as a popular solution to the incessant quest for increased capacity in modern wireless communication systems. It promises enormous capacity with a marginal increase in cost and complexity. This technology is now poised to penetrate large-scale commercial wireless products and networks such as broadband wireless access systems, wireless local area networks (WLAN), third-generation (3G) networks and beyond [2].

A MIMO system comprises a wireless communication link with multiple antenna elements in both transmitter and receiver as illustrated in Figure 1. A vector of signals is transmitted from the transmitter antenna array simultaneously and then travels through the wireless channel. These signals are then received at the receiver antenna array which combines the signals in such a way that the quality of the communication in terms of BER and data rate is significantly improved for each MIMO user. MIMO systems are based on a space-time signal processing architecture where time is complemented with space or distance which is obtained from the spatial distribution of antennas in the transmitter as well as the receiver. Space-time processing in MIMO systems basically increases data rate (spatial multiplexing) and link reliability (space-time coding).

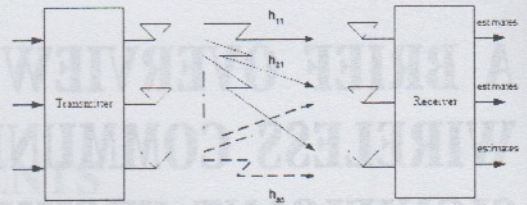


Figure 1 A MIMO Communication System Model

An interesting feature of MIMO is that it exploits the multipath scenario, a pitfall of wireless transmission communication, to its advantage. MIMO benefits from it by transmitting data on multiple signal paths which increases the amount of information transferred in a system which in turn increases the number of users it can serve. Some of the key advantages of MIMO communication can be identified as follows.

Extraordinary high spectral efficiency (from 30-40 bit/s/Hz) and large fade level reduction 10-30 dB) are the prime advantages [5]. Among other benefits that the system provides re a reduction in co-channel interference (5-15 dB), a flexible architecture through Digital Signal Processing (DSP) and diversity order, which is two times higher in MIMO than in Single-Input Multiple-Output (SIMO).

MIMO System Equation

In a single user MIMO model with N transmit and M receive antennas, the MIMO system equation is given by

$$\begin{bmatrix} r_1 \\ r_2 \\ \vdots \\ r_M \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & \Lambda & h_{1N} \\ h_{21} & h_{22} & \Lambda & h_{2N} \\ \vdots & \vdots & \vdots & \vdots \\ h_{M1} & h_{M2} & \Lambda & h_{MN} \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \\ \vdots \\ s_N \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_M \end{bmatrix}$$

or in matrix form

$$r = Hs + n \quad (1)$$

where H is the channel matrix of size M x N, r is the M x 1 received signal vector, s is the N x 1 transmitted signal vector, and n is an M x 1 additive white Gaussian noise vector with zero mean and variance $\hat{\sigma}^2$. The channel matrix H is the factor by which the signal is amplified and is also known as the channel coefficient. The element h_{ij} in the channel matrix H represents the complex gain between transmitter antenna j and receiver antenna i.

Principles of Space-time (MIMO) Systems

Consider the multiantenna system diagram in Figure 1. A compressed digital source in the form of a binary data stream is fed to a simplified transmitting block encompassing the functions of error control coding and mapping to complex modulation symbols (BPSK, QPSK, QAM, etc.). The latter produces several separate symbol streams which range from independent to partially redundant to fully redundant. Each is then mapped onto one of the multiple TX antennas. Mapping may include linear spatial weighting of the antenna elements or linear antenna space-time precoding. After upward frequency conversion, filtering and amplification, the signals are launched into the wireless channel. At the receiver, the signals are captured by possibly multiple antennas and demodulation and demapping operations are performed to recover the message. The level of intelligence, complexity, and a priori channel knowledge used in selecting the coding and antenna mapping algorithms can vary a great deal depending on the application. This determines the class and performance of the multiantenna solution that is implemented [6].

In the conventional smart antenna terminology, only the transmitter or the receiver is actually equipped with more than one element, being typically the base station (BTS), where the extra cost and space have so far been perceived as more easily affordable than on a small phone handset. Traditionally, the intelligence of the multiantenna system is located in the weight selection algorithm rather than in the coding side although the development of space-time codes (STCs) is transforming this view.

Simple linear antenna array combining can offer a more reliable communications link in the presence of adverse propagation conditions such as multipath fading and interference. A key concept in smart antennas is that of beamforming by which the average signal-to-noise ratio (SNR) is increased through focusing energy into desired directions, in either transmit or receiver [6].

Indeed, if one estimates the response of each antenna element to a given desired signal, and possibly to interference signal(s), one can optimally combine the elements with weights selected as a function of each element response. One can then maximize the average desired signal level or minimize the level of other components whether noise or co-channel interference.

Another powerful effect of smart antennas lies in the concept of spatial diversity. In the presence of random fading caused by multipath propagation, the probability of losing the signal vanishes exponentially with the number of decorrelated antenna elements being used. A key concept here is that of diversity order which is defined by the number of decorrelated spatial branches available at the transmitter or receiver. When combined together, leverages of smart antennas are shown to improve the coverage range versus quality tradeoff offered to the wireless user [6].

As subscriber units (SU) are gradually evolving to become sophisticated wireless internet access devices rather than just pocket telephones, the stringent size and complexity constraints are becoming somewhat more relaxed. This makes multiple antenna elements transceivers a possibility at both sides of the link, even though pushing much of the processing and cost to the network's side (i.e., BTS) still makes engineering sense [6]. Clearly, in a MIMO link, the benefits of conventional smart antennas are retained since the optimization of the multiantenna signals is carried out in a larger space, thus providing additional degrees of freedom. In particular, MIMO systems can provide a joint transmit-receive diversity gain, as well as an array gain upon coherent combining of the antenna elements (assuming prior channel estimation).

In fact, the advantages of MIMO are far more fundamental. The underlying mathematical nature of MIMO, where data is transmitted over a matrix rather than a vector channel, creates new and enormous opportunities beyond just the added diversity or array gain benefits. This was shown in [7], where the author shows how one may under certain conditions transmit independent data streams simultaneously over the eigenmodes of a matrix channel created by TX and RX antennas. However, to our knowledge, the first results hinting at the capacity gains of MIMO were published by Winters in [8].

MIMO Capacity

MIMO systems promise substantial improvements over conventional systems in both quality-of-service (QoS) and transfer rate. In addition to these benefits, it has been shown that MIMO offers absolute gains in terms of capacity bounds. Some fundamental results which compare single-input-single-output (SISO), single-input-multiple-output (SIMO), multiple-input-single-output (MISO) and MIMO capacities are discussed in the following

paragraphs.

Starting with a simple 1 x 1 memory-less SISO system, the capacity here is given by the expression [9]

$$C = \log_2(1 + \rho|h|^2) \quad (2)$$

where h is the normalized complex gain of a fixed wireless channel and $\hat{A}$ is the SNR at the receive antenna.

When the number of receive antennas is increased, the capacity of the system improves

with the increase in antenna numbers. Hence in the SIMO scenario, the capacity is

given by [9]

$$C = \log_2(1 + \rho \sum_{i=1}^M |h_i|^2) \quad (3)$$

where M is the number of receive antennas and h_i is the gain for each receive antenna. An interesting feature of equation (3) is that the average capacity of the system increases logarithmically with any increase in the value of M .

Similarly, in the case of MISO where the system has N transmit antennas, the capacity becomes [9]

$$C = \log_2(1 + \frac{\rho}{N} \sum_{i=1}^N |h_i|^2) \quad (4)$$

The normalization of the SNR by N ensures that a fixed total transmitter power is used. In this case as well, the average capacity of the system increases logarithmically with an increase in the value of N . This makes it evident that increasing the number of antennas in both transmitter and receiver will make the system capacity better, but only in a logarithmic way.

In the case of MIMO with antenna diversity at both receiver and transmitter, the expression for capacity is given by [8, 9]

$$C = \log_2[\det(I_M + \frac{\rho}{N} HH^H)] \quad (5)$$

where $(\cdot)^H$ means transpose-conjugate, I_M is the $M \times M$ identity matrix and H is the $M \times N$ channel matrix. It should be noted here that N equal power uncorrelated

sources are assumed at the transmitter.

An important conclusion drawn from equation (5) is that the mean capacity grows linearly with $m = \min(M, N)$ [6] rather than logarithmically as in equations (3) and (4).

Spatial Multiplexing Detection

As mentioned earlier, MIMO exploits spatial multiplexing techniques in which multiple data streams are transmitted simultaneously and on the same frequency from the transmitter, which may or may not have the channel state information (CSI), using an antenna array.

The detection operation at the receiver end of the MIMO link is called Spatial Multiplexing Detection (SMD). SMD is basically an operation in which the received signals are combined to obtain an estimate of the transmitted signal. SMDs are basically classified into two categories viz linear detection and non-linear detection.

Linear Detection

Linear detection is relatively simple to implement and has less computational complexity which in turn reduces the processing time in the receiver. However, these receivers have intermediate performance. Some of the common types of Linear Detection techniques are Selection Combining (SC), Equal Gain Combining (EGC), Maximum Ratio Combining (MRC), Zero Forcing (ZF) and Minimum Mean Squared Error detection (MMSE).

Linear detection is a simple process in which the received signal vector is multiplied with a weight matrix to produce the signal estimate.

$$\tilde{s} = W^H r \quad (6)$$

where $(\cdot)^H$ denotes hermitian transposition. The weight matrix W is chosen at our disposal. The weight matrix varies according to the particular linear detection scheme employed. Note that $\tilde{s}$ will be quantized to produce the signal estimate $\hat{s}$.

Zero Forcing

Zero Forcing (ZF) is a linear spatial multiplexing detection scheme which is simple and widely used. As the name suggests, this scheme forces the interference to zero. However, it may sometimes result in noise inflation. The weight matrix for ZF is given by

$$W^\psi = H^{-1} \quad (7)$$

for a system with same number of transmit and receive antennas ($M = N$) and

$$W^\psi = (H^\psi H)^{-1} H^\psi \quad (8)$$

From the above equation, it can be concluded that although ZF nullifies all the interference it has the potential problem of noise enhancement.

Minimum Mean Squared Error

Improved performance compared to ZF can be obtained by attempting to minimize both interference and noise at the same time. This is done by the Minimum Mean Squared Error (MMSE) detection scheme, which is a trade off between noise inflation and interference suppression. The weight matrix for MMSE detection when it is assumed that $E|s_{ij}|^2 = 1$ is given by

$$W^\psi = H^\psi (\sigma^2 I_M + H H^\psi)^{-1} \quad (9)$$

which is also equivalent to

$$W^\psi = (\sigma^2 I_N + H^\psi H)^{-1} H^\psi \quad (10)$$

where I_M and I_N are the $M \times M$ and $N \times N$ identity matrices respectively.

It can be seen that in this case, interference is not totally nullified as in the case of ZF but the noise term is less inflated than that of ZF.

Optimal Detection

Maximum Likelihood (ML) is the optimal detection scheme but it has very high computational complexity and hence becomes the most time consuming detection procedure. The procedure is non-linear and basically consists of a search through all possible signal vectors.

Maximum Likelihood

ML is the optimal detection scheme and has a high computational complexity. Although the performance is superior to any other linear detection techniques, it is the most time consuming detection procedure. Moreover, its complexity increases with increases in the number of antennas or the size of the signal constellation.

The ML detector has the desirable property that, under the statistical assumption on s being i.i.d. random variables uniformly distributed over a constellation S , it minimizes the probability of error,

$$P_e = P(s \neq \hat{s}) \quad (11)$$

The likelihood of $\hat{s}$ is obtained by minimizing noise power, the ML estimate of s , i.e.

$\hat{s}_{ML}$, is given by

$$\hat{s}_{ML} = \arg \min_{\hat{s} \in S^N} |r - H\hat{s}|^2 \quad (12)$$

Thus, the ML detector chooses the message $\hat{s}$ which yields the smallest distance between the received vector r , and hypothesized message $H\hat{s}$.

Simulations and Results

In the previous section, various spatial multiplexing detection schemes are described in detail. This section presents comparisons between BER for the different detection schemes. The results presented here are obtained from Monte-Carlo simulations performed in MATLAB. The channel is considered to be at fading Rayleigh and the modulation scheme to be BPSK for simplicity in simulation.

Figure 2 shows a comparison in terms of BER for different SNR conditions for different detection schemes in a 4-4 MIMO link. It is clearly revealed in Figure 2 that ML has the best performance being an optimal detection scheme.

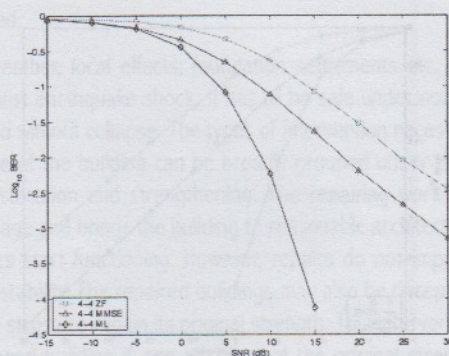


Figure 2 Comparison of BER for ZF, MMSE and ML in a 4-4 MIMO link

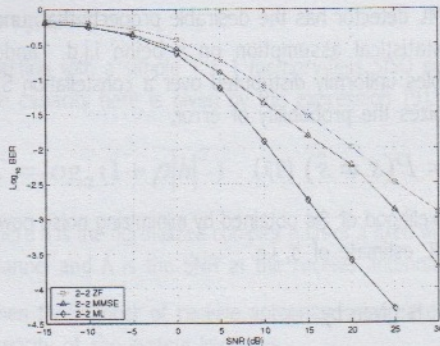


Figure 3 Comparison of BER for ZF, MMSE and ML in a 2-2 MIMO

ZF is observed to have the worst performance of all.

Similarly, Figure 3 and Figure 4 show comparison of BER in different SNR conditions for different detection schemes in a 2-2 and 6-6 MIMO link. The pattern of the curves is similar to the 4-4 scenario, but it is seen that the system performance increases in any detection scheme as the number of antennas is decreased. Figure 5 is an example of this in which the MMSE detection scheme is shown for 6-6, 4-4 and 2-2 MIMO links.

Conclusions

This paper reviews the major features of MIMO links for use in future wireless networks. We see that the great capacity gains which can be realized from MIMO. Whether we achieve this fully or at least partially in practice depend on a sensible design of transmit and receive signal processing algorithms. It is clear that the success of MIMO algorithm integration into commercial standards such as 3G, WLAN, and beyond will rely on an implementation of appropriate diversity and detection

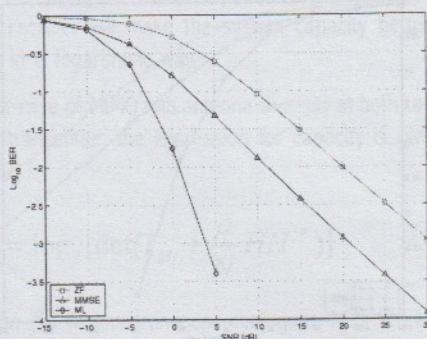


Figure 4 Comparison of BER for ZF, MMSE and ML in a 6-6 MIMO link

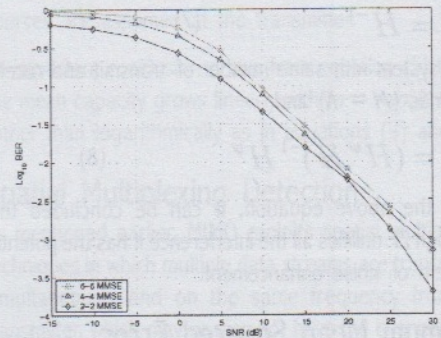


Figure 5 Comparison of BER for 6-6, 4-4 and 2-2 MIMO links using MMSE

schemes.

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RETROFITTING OF MASONRY STRUCTURES

Er. Prachand Man Pradhan*

Introduction

From the global earthquake perspective, the masonry buildings have proved to be the most vulnerable to seismic forces. The past India, Pakistan and Nepal earthquakes have shown that major loss of lives and properties was due to weak masonry structures.

In Nepal, majority of buildings in rural as well as in sub-urban areas are made of mud, rubble and un-reinforced brick masonry. Masonry is a term covering wide range of materials such as adobe, brick, stone, hollow concrete blocks, wood posts and thatched roof or combination of some or all the above materials. The Pagoda type temples, mostly built during the Malla regime, comprise mud mortar, timber and brick masonry. Constructions of such structures are done by local builders in a traditional manner, using local construction practices and materials. No strength calculations or engineering practice is involved in construction of such buildings. The strength of such buildings and temples were judged by the 1934 Bihar Nepal earthquake of Magnitude 8.4, in which a devastating scenario was observed then. Such failure of structures, due to lack of strength and ductility against earthquake force have proved to be disastrous time to time around the world. However, if some measures are taken, collapse of such buildings can be avoided and as such, large scale loss of life and property can be prevented.

Buildings decay due to weather, local effects, foundation settlements etc. If a building is to be safe against earthquake shock, it has to be safe under normal loads and resist lateral load without collapse. The types of intervention necessary to ensure the performance of the building can be broadly grouped under three categories like; repair, restoration and strengthening. The repairing work just rectifies the defect of damage and brings the building to reasonable architectural shape so that the services start functioning. However, repairs do not improve the structural strength or stability. The repaired buildings may also be deceptive. Restoration is to make the structure regain its original strength. This intervention is undertaken for a damaged building if one is sure that the original strength

* HOD, PG Dept. of EQ Engg., Khwopa Engineering College

provides an adequate level of safety for future earthquake. Some of the common restoration techniques are to remove partition or deceptive wall and rebuilding it with richer mortar, sealing cracks with epoxy mortar, adding wire mesh on either sides of a cracked component, crack stitching etc. with a view to strengthen the structure.

In Nepal, the reconstruction works of old temples and *patties* (public shelters in the name of religion) have been happening at different parts of the country; but generally, most of them are merely repaired and not retrofitted. Repairing is not sufficient to protect the structure from collapse in future earthquake.

Load Bearing Wall Buildings

Buildings in which the roof and floor slabs are directly supported on the walls are called load bearing wall buildings. These walls serve both as supports and partitions. These walls also need to resist the lateral load resulting from earthquake and wind. Generally, temples, *patties*, residential buildings up to 3 storeys or traditional structures are of this type. These walls possess sufficient resistance against in-plane action as they serve as shear walls; however they are weak in out-of-plane bending due to lack of tensile strength. In buildings, the walls act as box, and the walls parallel to lateral load, act as webs and the walls orthogonal to the load act as flanges. The box action involves considerable interaction between the web and flanges at corners of the building. During earthquakes, the damage initiates at corners, resulting in loss of box action and the walls start acting independently leading to collapse. Thus, the basic principle of seismic safety of load bearing wall buildings lies in their integral box action.

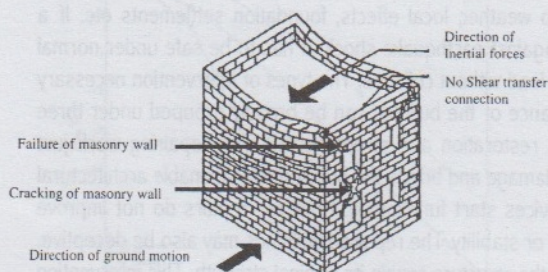


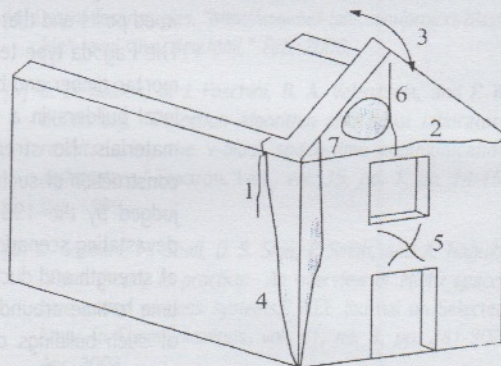
Fig.1: Failures in Masonry Buildings



Fig.2: Damaged Brick Masonry Building

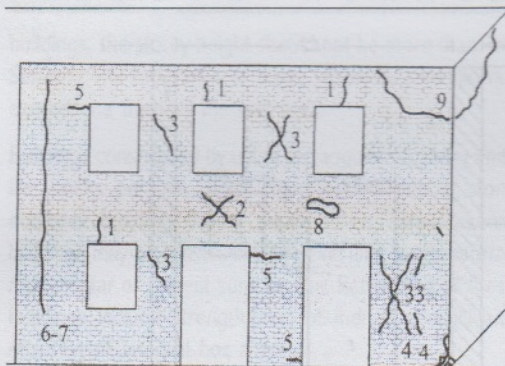
Weaknesses of Masonry Structures

The main weakness of load bearing wall buildings may be due to the openings that are provided for windows, doors etc. The openings result in reduction of effective cross sectional area or wall resisting lateral loads. The piers between the openings are subjected to high stresses than the portion of the wall above and below the openings. As such, generally, diagonal X shaped cracks originate from the corners of openings (Fig.8).



1. Vertical cracks in the corner and/or top
2. Horizontal cracks along the façade
3. Partial collapse of an exterior wall
4. Wythe separation
5. Cracks at lintel and top of the slender pier
6. Cracks at the level of roof
7. Masonry ejection

Fig.3: Out-of-Plane Failure (Zuccaro and Papa, 1999)



1. Vertical cracks on openings
2. Diagonal shear cracks on doors and window lintels
3. Diagonal shear cracks in the masonry piers between openings
4. Crushing of corners of walls due to excess of compression stress
5. Horizontal flexure cracks on top & or /base of masonry piers
6. Vertical cracks at wall intersections
7. Passing through vertical cracks at wall intersections
8. Spalling of material at the location of floor beam due to pounding
9. Separation and expulsion of the intersection zone of two corner walls

Fig.4: In-plane Failure (Pasquale and Orsmi, 1999)

The shape of the building and regularity and continuity of construction are also important for seismic safety of buildings. Asymmetric buildings undergo torsion and result in warping of walls, which in turn, results in out-of-plane failure (Fig.3). Continuity of construction particularly at joints and corners is very important due to interaction between different component walls at these locations.

Apart from these, there are several other reasons of weaknesses of load bearing wall buildings, such as gable roofs, long walls, poor strength materials, weak workmanship etc. The typical crack in masonry runs along the mortar joints, passes below the brick and above the mortar mixture, without breaking the bricks themselves. This is due to the lesser strength of the mortar. Heavy roofs, large floor height, weak foundations may also be the weaknesses of masonry buildings during earthquakes.

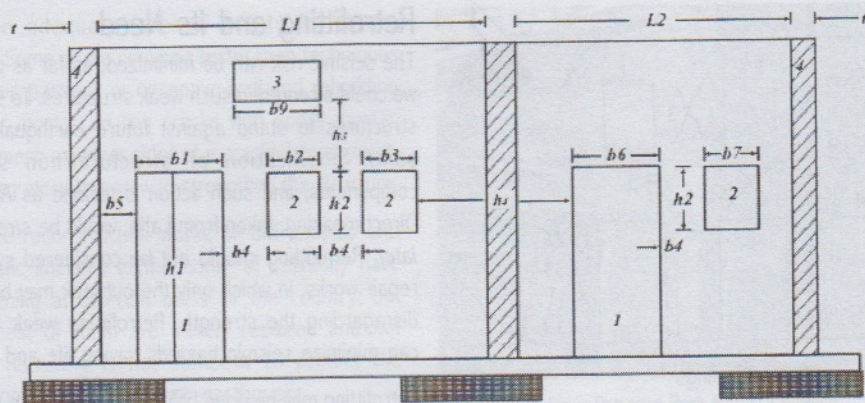
Retrofitting and its Need

The seismic risk can be minimized, as far as possible, if we could strengthen such weak structures. To strengthen structures to stand against future earthquakes needs some modification of structural/non structural components, and such action is termed as *Retrofitting*. Direct meaning, taken from Latin, would be *strengthening later*. Retrofitting should not be considered synonym to repair works, in which only the out look may be rectified disregarding the strength. Retrofitting weak structures can minimize seismic hazards saving life and property.

Retrofitting may be done before an earthquake to prevent damage or after an earthquake in combination to repair of the damaged components. Once it is realized that a particular building is weak against earthquake forces, retrofitting action should be taken. Retrofitting of building is generally more economical as compared to demolition and reconstruction. Thus, seismic retrofitting of structure is one of the most important aspects for mitigating seismic hazards, mainly in earthquake prone country like Nepal.

The need of retrofitting of existing building may arise due to various reasons. Buildings designed according to old codes may require retrofitting. Retrofitting may also be required to buildings though designed considering new code but having deficiencies in design and construction. Similarly, essential buildings like hospitals, monumental structures or important buildings whose service is assumed to be essential just after an earthquake may require retrofitting. Sometimes buildings are designed for one purpose but may be used for different purposes, as such; they are required to be strengthened.

After a severe earthquake, it is necessary to make an immediate diagnosis of the general condition of the structure in order to avoid any risk to human life and psychological effects on the population. After an earthquake, structures undergo large deformations and loose their strength to stand against future earthquakes. Thus, a structure which resisted an earthquake force of large magnitude may not be able to resist future earthquake of even lesser magnitude. Once a structure undergoes deformation due to an earthquake force, its strength will be drastically deteriorated and the owner should ponder whether his building should be strengthened or not. It is thus, necessary to enhance the strength of the deteriorated structure. But, beforehand, the urgent measure consists of bracing the structures and reducing the loads after it suffers earthquake force.



1 Door	$b1+b2+b3$ $0.5L_1$ one storey	$b6+b7$ $0.5L_2$: one storey	$b4$ $0.5L_2$ but not less than 600mm
2 Window	$0.4L_1$ two storey	$0.40L_2$: two storey	$b5$ $0.25L_1$ but not less than 600mm
3 Ventilator	$0.33L_1$ three storey	$0.33L_2$: three storey	$b9$ 600mm $0.5x(b2$ or $b3)$ whichever is more
4 Cross wall			

Source: Guidelines of Retrofitting of Buildings. UNDP/Government of Tamilnadu, India.

Fig.5: General Requirements of Openings

Criteria of Retrofitting

There are various techniques developed for seismic retrofitting and the concept behind such techniques are upgrading the lateral strength of structures, increasing ductility and strength of structures. These may be termed as Technical Criteria. In addition to the technical criteria, there is some General Criteria too. The decision to repair and retrofitting also depend on various factors like cost/benefit analysis, available workmanship and material, aesthetics, architectural identity of historical buildings, duration of work etc.

Strengthening of building either involves in component strength enhancement or structural system modification or both. The overall strength of building may be improved by the following ways:

- Increasing the lateral load resistance by reinforcing or by introducing new wall and columns.
- Introducing the continuity between the components of the structure to achieve ductile performance. This is done by connecting wall with roof, wall with wall, including band and ties between walls.

- Eliminating weakness in an existing building by introducing symmetry in plan, changing location of mass, reducing large openings etc.
- Avoiding brittle mode of failure. This is done by improving anchorage and providing bracings in walls.

Retrofitting of Brick Masonry Buildings

Retrofitting is done to those structures which are assumed as vulnerable to future earthquakes. There are certain factors which are to be looked upon before deciding whether a building needs retrofitting or not. If the building is located in slopy ground care has to be taken to see if there are visible cracks in the walls. Similarly, if the building is located on reclaimed soil (filled soil), it will be necessary to rectify the foundation. If the roofing consists of gables, it also needs strengthening. A masonry building would be considered good if lintel bands are provided in the roof level, foundation level and lintel level; however, residential buildings are usually not constructed in this manner. It would also be better to provide retrofitting on walls to correct these errors. For un-reinforced masonry

buildings, the storey height should not be more than 3m. Similarly, the total area of holes (openings) should not exceed one third of the wall area.

Buildings constructed by using rectangular masonry units like bricks perform better than random rubble stone masonry building during earthquakes. The masonry buildings may be constructed by using lime-surkhi mortar, mud mortar or cement sand mortar. Retrofitting of these buildings include strengthening of individual walls and ensuring of integral box action.

Strengthening walls in a building basically deals with the quality of construction, unsupported length and height and size and placing of openings. Visual inspection of masonry units and mortar may be sufficient for quality and strength evaluation. If the walls have cracks, voids, loose pockets or mortar degradation, strengthening can be done by grouting. Grouting can be done using shrinkage compensating cement slurry, basically for ordinary buildings or using polymer grouts or epoxy for important buildings like temples, monumental structures (as they are expensive). Large voids can be directly filled by shrinkage compensating cement sand mortar or polymer modified mortar. For fine cracks up to 1mm width, epoxy injection is preferred.

In case of weak masonry and absence of enough solid piers to resist seismic loads, shotcrete of 4 to 5 inches thick may be provided to the walls either outside or inside. Shotcrete is a concrete mix, either in wet condition (for large volumes and massive sections) or in dry condition (gunite) for lesser volumes, thin sections and confined spaces, pneumatically applied to a wall.

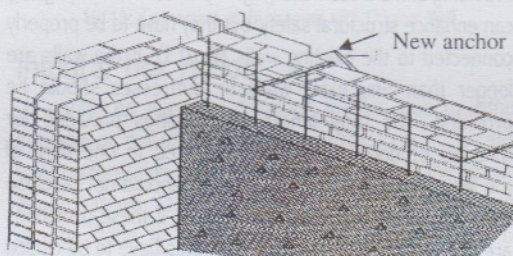


Fig.6: Strengthening of Existing Wall with Shotcrete.

Grouting Procedure:

- i) The plaster from the area to be grouted is removed and holes are drilled (2-4 holes per square meter).

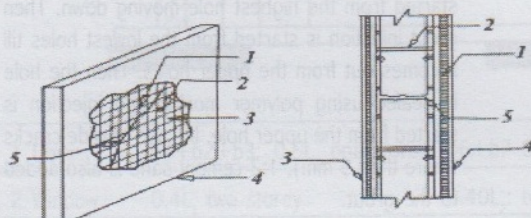
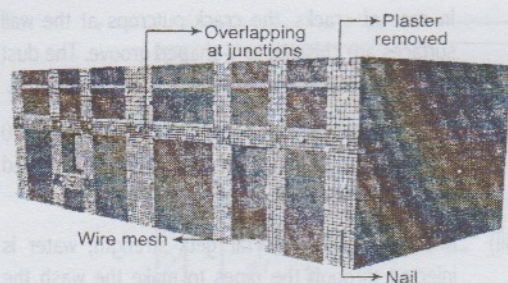
In case of cracks, the crack outcrops at the wall surfaces are chiseled to V-shaped groove. The dust and loose materials are removed by air blasting.

- ii) Plastic or aluminum pipes (12mm dia. and 30-40 mm long) are placed in the drilled holes and sealed by polymer mortar.
- iii) After the sealing mortar gets strength, water is injected through the pipes to make the wash the dust and saturate the masonry. Water injection is started from the highest hole moving down. Then grout injection is started from the lowest holes till it comes out from the upper holes. Then the hole is sealed using polymer mortar and injection is started from the upper hole. In case of wide cracks (more than 5 mm), 1:2 cement sand is also added to the grout.
- iv) The pipes are cut off after the grout sets and the surface is plastered.

To provide additional strength to severely damaged walls, Ferro-cement plate can be provided on both the faces of walls (Fig.7). It is simply the overlaying micro concrete on top of plaster work including galvanized wire mesh. Ferro-cementing is done using the following steps:

- i) the plaster on both sides of the walls is removed, the mortar joints are raked out up to 15-20 mm depth, surface is cleaned and wet with water and a coat of cement slurry or polymer enhanced cement is applied.
- ii) A 10mm thick coat of cement sand plaster (1:3 cement-sand or 1:1.5:3 micro-concrete) is applied. The surface of plaster is roughened to have good bond with the second coat.
- iii) Welded wire mesh is fixed on the surface of plaster using 150mm long nails. The wire-mesh and nails are galvanized to protect them from corrosion. After fixing the wire-mesh, second coat of plaster or micro concrete (16-20mm thick) is applied.

Masonry walls can also be strengthened by epoxy gluing the Fiber Reinforced Plastic (FRP) strips. FRP is becoming popular these days due to its unique properties like high strength to weight ratio, stiffness to weight ratio, corrosion and fatigue resistance as against conventional materials. FRP consists of stiff and strong reinforcing fiber mainly carbon and glass held together. Various types of FRP



1. Wire mesh on front face
2. Clamps
3. Wire mesh on back face
4. Cement plaster
5. Crack

Fig.7: Strengthening by Ferro-cement

are like Carbon Fiber Reinforced Plastic sheets (CFRP) and Glass Fiber Reinforced Polymer (GFRP) sheets are the latest developments in the present context. The ultimate tensile strength of Carbon Fiber (T700S) is 2300 N/mm^2 , which is significantly high in comparison to materials like steel or concrete. Steel's Ultimate tensile strength is 235 N/mm^2 .



Fig. 8: Cracks between openings

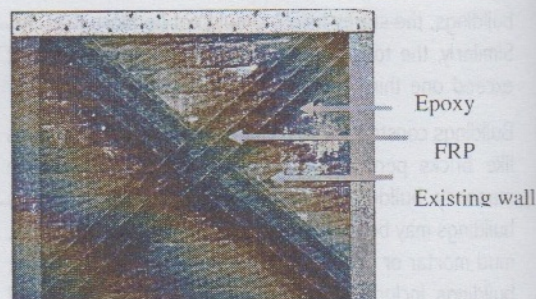


Fig.9: using FRP Strips on masonry walls

The method of strengthening a load bearing masonry wall with FRP is quite simple and rapid. The surface should be roughened by grinding and then cleaned with high air pressure blasting. The holes should be filled with epoxy mortar. The FRP sheets are fixed to the surface of masonry by epoxy resin on one or both sides of the wall (Fig.9). Steel plates are used to ensure non-occurrence of anchorage failure by anchoring the FRP to the slab and foundation pad. Anchoring in slab avoids stress concentration in masonry walls. The anchoring of sheets in the RC slab consists of steel plate pressed on to the ends of the sheets by means of bolts. The application of FRP sheets to the existing load bearing masonry wall increases its lateral resistance and ductility. It can be used to damaged structures or historical buildings.

Amendments in Lengths and Openings

Since large openings, long walls (more than 5m), large heights of floors are deficient in terms of earthquake resistance, they have to be corrected. The cracks generally propagate from corners of openings (Fig.8). Providing extra cross walls (Fig.11) or buttresses (Fig.12) can enhance structural safety, but they have to be properly connected to the existing walls (Fig.13). If the walls are longer than 5m, extra walls or buttresses should be provided. The total length of openings provided for windows or doors should be restricted to one third of the length of the wall. The openings should not be close than 600mm to each other or corners. If these conditions are not satisfied, some of the openings have to be closed completely or partially providing proper bond between old and new construction (Fig. 10).

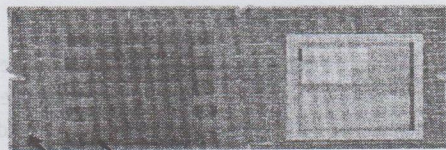


Fig.10: Closing of an Opening

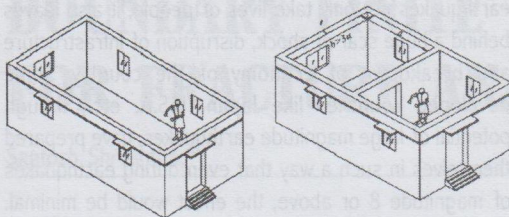


Fig.11: Supporting Long Walls by Cross Wall

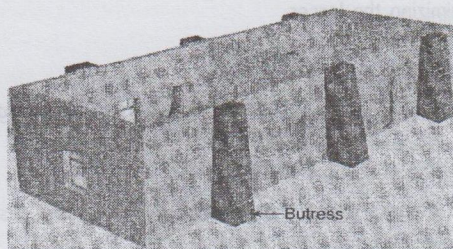


Fig.12: Supporting Long Walls by Buttresses

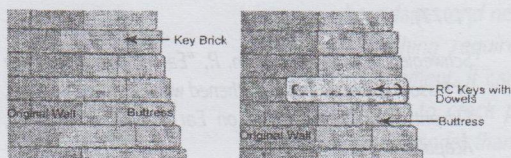


Fig.13: Connection of Buttresses with Original Wall

Integral box Action

Un-reinforced masonry develops tension due to either in-plane or out-of-plane bending. Pre-stressing creates axial compression in the wall which suppresses the tension due to above causes. Pre-stressing the existing walls can be done to achieve box action. This is done by placing steel rods connected to anchor placed which is bolted tightly to provide pre-stressing action to the walls (Fig.14, 15). The pre-stressing bars can be inserted in pairs on opposite sides of a wall so that out-of-plane is prevented. The basic idea behind it is to tie up the whole structure and let it sway in such a way that the bond between the connectivity do not separate.

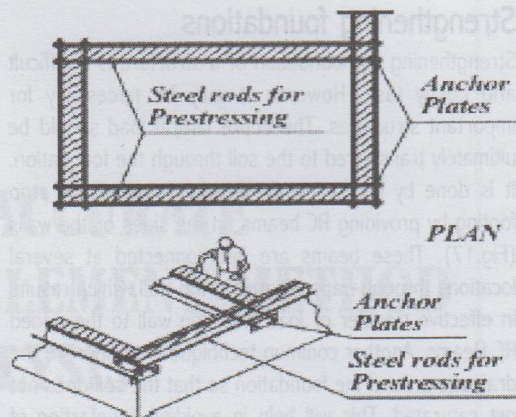


Fig.14: Strengthening of Walls by Pre-stressing (IS: 13935-1993)

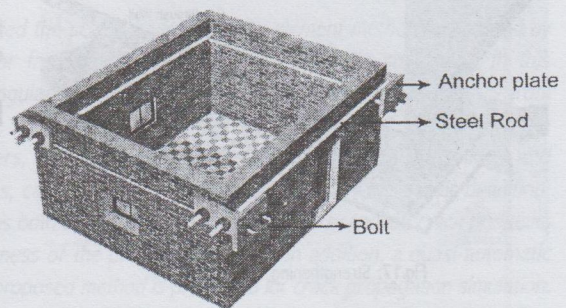


Fig.15: Pre-stressing of Masonry Walls

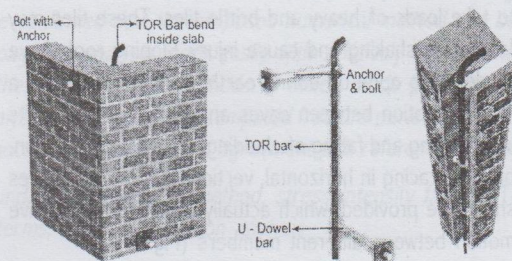


Fig.16: Corner Reinforcement

Another method consists of addition of vertical reinforcements on the corners of the wall connections. Vertical reinforcement can also be added in the form of steel bars in the corners to achieve integral box action (Fig.16). The bar has to be properly connected with walls, roof/floor and is to be grout-anchored to the foundation.

Strengthening foundations

Strengthening the foundation of a structure is a difficult and costly task. However, it may be necessary for important structures. The entire lateral load should be ultimately transferred to the soil through the foundation. It is done by increasing the bearing area of the strip footing by providing RC beams on the sides of the walls (Fig.17). These beams are interconnected at several locations through gaps created in the wall, which results in effective transfer of load from the wall to the added RC Beams. Another common technique is to improve the drainage around the foundation so that the soil does not get saturated. This will help in avoiding liquefaction of soil.

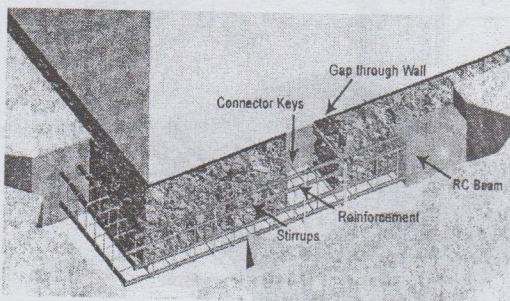


Fig.17: Strengthening of Foundation

Retrofitting of Roofs and floors

Gabled or pitched roofs are considered the most vulnerable during earthquakes. Generally, these roofs have to take loads of heavy and brittle tiles. These tiles may fall during shaking and cause injury. Sloping roofs have tendency to open up during earthquakes and there is a relative motion between eaves and crown which results in loosening and falling of cladding. To avoid such action, proper bracing in horizontal, vertical and inclined planes should be provided, which actually minimize the relative motion between different members (Fig.19).

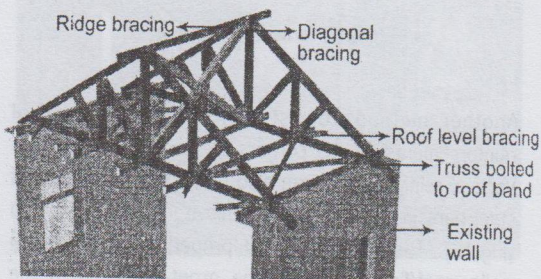


Fig.19: Horizontal and vertical bracing in sloping roofs

Concluding Remarks

So far, in Nepal, there is very less retrofitting work being practiced, however, its need seems to be rising due to the potential big earthquake which is being expected in the Himalayan region. Action taken on time can save huge loss of life and property. Few monumental buildings/temples have already been retrofitted, but a lot more are waiting for strengthening. Disastrous events from earthquakes not only take lives of people, it also leaves behind a huge scar of shock, disruption of infrastructure and breakdown of economy of the country. Some developed countries like Japan, U.S.A. etc., though potential of large magnitude earthquakes, have prepared themselves in such a way that even during earthquakes of magnitude 8 or above, the effect would be minimal. Retrofitting the needy structures is one of the preparedness actions that can play major role in minimizing the losses.

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AN EFFICIENT AND ACCURATE BOUNDARY FINITE ELEMENT METHOD FOR FRACTURE ANALYSIS

Santosh Shreshtha,*

Abstract

This paper is applied the scaled boundary finite element method, developed by Song and Wolf, for fracture analysis of 2D linear-elastic structures. In this method, stress singularity at a crack tip can be derived semi analytically from its stress solution. By using the semi-analytical properties of the method, the fracture parameters, not only stress intensity factors but also T-stress and higher order terms, can be more easily computed directly from their definition. Numerical examples both bounded and unbounded with branched crack problems show the effectiveness of the proposed method. In addition, a quasi-automatic procedure of the proposed method is presented for crack propagation simulation. Since only the domain boundary is required to discretize like in boundary element method and also it has its own unique property that the side-face boundaries and near crack tip are not necessary to discretize, the burdensome remeshing required in FEM and BEM is minimized. By simple remeshing requirement, it can be confirmed that the proposed numerical method can be applied to crack propagation analysis more easily with relatively coarse and simple model than other computational methods. A mixed mode problem for crack propagation analysis is simulated. The computed fracture parameters and crack propagation trajectories are in excellent agreement with reference results.

Keywords: *scaled boundary finite element method, stress intensity factors, T-stress, higher order terms, crack propagation analysis*

Introduction

Prevention of failure of structures and structural components has always been a major concern in engineering. While there are many possible causes for structural failure, much attention has been given to fracture of materials over the past few years. Numerous incidences involving sudden failure of structures due to fractures have been recorded in the history of structural technology. A

* PhD Candidate, Department of Civil and Environmental Engineering, Ehime University, Japan
Email : santosh_pshrestha@yahoo.com

complex process of crack initiation, growth and fracture pattern formation can lead to failure of structural components and, in worst case, collapse of an entire structure or system. Therefore, in failure analysis of structures, understanding and accurate modeling of the fractural process is vital to estimate the loading capacity and the remaining life of the cracked structural components, and to increase the serviceability of structures.

For fracture analysis of a crack, finite element method (FEM), boundary element method (BEM) and meshless method are the most widely used numerical methods. However, studies have found that these methods have some limitations and are inefficient to model the crack problems especially for crack propagation simulation. In FEM, a fine mesh around the crack-tip is generally required to compute the singularity in the stress field that leads to increase computational cost. Over the past few decades, researchers have been proposed different numerical techniques such as adaptive finite element meshes, various mesh overlap procedures and extended finite element method (XFEM; Sukumar & Prevost (2003)) to model the crack problems more efficiently. On the other hand, BEM has some advantages over FEM and is firmly established for fracture analysis. However, it needs complicated mathematics procedures with fundamental solution, which limits the applicability of BEM. More recently, the dual boundary finite method (Portela, & Aliabadi, (1992)), displacement discontinuity BEM (DDBEM; Yan (2004)) and green function BEM (Silveira, et al. (2005)) seems to be an efficient way of modeling crack problems in BEM. The meshless method is very flexible concerning geometrical updating of the model but it does not delete the necessity of the modal rearrangement to keep the accuracy of the calculation during crack propagation. According to Rao and Rahman (2001), a meshless method is more computationally costly than a regular FEM. Therefore, even though much achievement has been made in crack modeling techniques, both simple and very accurate crack modeling techniques still need to be developed, in particular for crack propagation.

A recently developed scaled boundary finite element method (SBFEM), which attempts to combine the advantages of FEM and BEM with unique properties of its own, is emerging as an alternative numerical method for fracture analysis. This method has ability to semi-

analytically compute stress and displacement field of singularities region at the so-called 'scaling center' of the bounded domain when this center lies on the interested point (Wolf, 2003). By using the semi-analytical properties, authors (Shrestha & Ohga, 2005, and Shrestha & Ohga, 2006a) and other researchers (Song & Wolf, 2002, Song, 2005, Chidgze & Deeks, 2005) have applied the SBFEM computing the fracture parameters: stress intensity factors (SIFs), the *T*-stress and higher order terms of the crack tip fields. To our knowledge, none of the previous studies have addressed the branched crack problems and crack propagation analysis using this method.

The main aim of this paper is to demonstrate the effectiveness of the proposed method for fracture parameters computation and to extend the application of the method to branched crack problem and crack propagation simulation. A quasi-automatic procedure is presented for crack propagation simulation. Since only the domain boundary is required to discretize like in BEM and also it has a unique property that certain fixed and free (side faces) boundaries and near crack tip are not necessary to discretize, the burdensome remeshing required by FEM and BEM is minimized. By semi-analytical computation of stress singularity with high accuracy and simple remeshing requirement for crack propagation, it can be confirmed that the proposed numerical method can be applied to fracture analysis more easily with relatively coarse and simple model than other computational methods. Three crack problems – bounded with straight cracks and unbounded with branched cracks are simulated to compute fracture parameters i.e. SIFs, *T*-stress and higher order terms of near crack-tip stress fields and a benchmark problem of a mixed mode crack problem is considered to simulate crack propagation. The computed fracture parameters and crack propagation trajectory are in excellent agreement with reference results.

Scaled boundary finite element method

The scaled boundary finite element method is a new semi-analytical fundamental solution-less BEM based on FEM (Wolf, 2003). In this method, the partial differential equation of a variety of linear problems is transformed into ordinary differential equations. Then, these ordinary differential equations are solved analytically in radial direction and the coefficients of these equations are

determined by the finite element approximation in the circumferential directions. The virtual work derivations of the stress and displacement fields in the method are presented in detail in Deeks & Wolf (2002), but are summarized here for convenience as follows.

2.1. Governing equations of elastostatics

For two-dimensional elastostatics problems, the strains $\{\epsilon(x, y)\}$ related to the displacement $\{\delta u(\delta x, \delta y)\}$.

$$\epsilon(x, y) = \begin{Bmatrix} \epsilon_x \\ \epsilon_y \\ \gamma_{xy} \end{Bmatrix} = \begin{Bmatrix} \frac{\partial}{\partial x} & 0 \\ 0 & \frac{\partial}{\partial y} \\ \frac{\partial}{\partial y} & \frac{\partial}{\partial x} \end{Bmatrix} \begin{Bmatrix} u_x \\ u_y \end{Bmatrix} = [L]\{u(x, y)\} \quad (1)$$

where $[L]$ is linear differential operator.

And the stresses $\{s(x, y)\} = [s_x, s_y, t_{xy}]^T$ are given by

$$\epsilon\{\sigma(x, y)\} = [D]\{\epsilon(x, y)\} = [D][L]\{u(x, y)\} \quad (2)$$

with the elasticity matrix $[D]$.

In no body load case, the internal equilibrium in elastostatics leads to the differential equation

$$[L]^T \{\sigma(x, y)\} = 0 \quad (3)$$

which must be satisfied at every point within the domain.

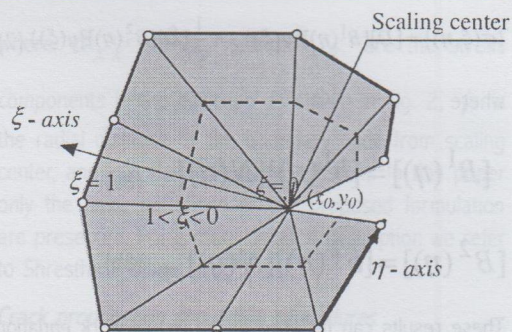
Scaled boundary coordinate system In this method, a coordinate system consists of a radial direction (ξ) and a local circumferential direction (η) is introduced (Fig. 1). The radial coordinate is defined to be zero at 'scaling center (SC)', unit value on the domain boundary and to have infinity for far field. The circumferential coordinate measures the distance anticlockwise around the boundary. The coordinate system is termed the scaled boundary coordinate system, and related to Cartesian coordinate by the following relations.

$$x = x_0 + \xi x(\eta) \quad (4a)$$

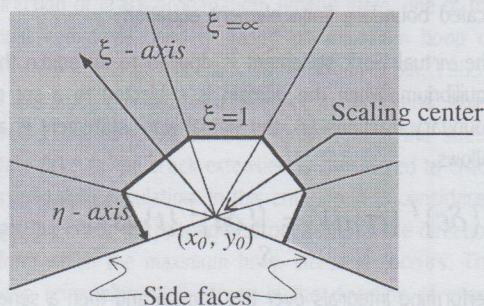
$$y = y_0 + \xi y(\eta) \quad (4b)$$

where $x(\eta)$ and $y(\eta)$ are the functions describing the variation of the boundary in x and y directions as functions of η .

Applying standard procedures to transform the geometry



a) Bounded domain



(b) Unbounded domain

Figure 1. Scaled boundary coordinate system

from Cartesian co-ordinates to the scaled boundary co-ordinates defined in above Eq. (4), the linear operator in Eq. (1) can be written in the co-ordinate ξ, η as

$$[L] = [b^1(\eta)] \frac{\partial}{\partial \xi} + \frac{1}{\xi} [b^2(\eta)] \frac{\partial}{\partial \eta} \quad (5)$$

where $[b^1(\eta)]$ and $[b^2(\eta)]$ depend only on the geometry of the boundary.

Displacement function

The displacements at any point in the domain defined by scaled boundary coordinates ($\delta x, \delta y$) can be expressed in the following form.

$$\{u(\xi, \eta)\} = \sum_{i=1}^n N_i(\eta) \{u_i(\xi)\} = [N(\eta)] \{u(\xi)\} \quad (6)$$

which represents a discretisation of the boundary only.

Substituting Eqs. (5) and (6) in Eq. (3) lead to the approximate stresses in the co-ordinates $\delta x, \delta y$ as

$$\{\sigma(\xi, \eta)\} = [D][B^1(\eta)]\{u(\xi)\}_{,\xi} + \frac{1}{\xi}[D][B^2(\eta)]\{u(\xi)\} \quad (7)$$

where

$$[B^1(\eta)] = [b^1(\eta)][N(\eta)] \quad (8a)$$

$$[B^2(\eta)] = [b^2(\eta)][N(\eta)],_{\eta} \quad (8b)$$

These results can be used in the virtual work equation to solve for the radial displacements

Scaled boundary finite element equation

The virtual work statement is applied to introduce the equilibrium. When the domain is subjected to a set of boundary tractions $\{t\}$, the virtual work statement is as follows.

$$\int_V \{\delta \epsilon\}^T \{\sigma\} dV = \int_S \{\delta u\}^T \{t\} ds \quad (9)$$

Performing integrals over the domain and then a series of mathematical manipulations, the virtual work statement is satisfied for all virtual displacements $\{\delta u\}$ when

$$[E^0]\xi^2\{u(\xi)\}_{,\xi\xi} + [[E^0] + [E^1]^T - [E^1]]\xi\{u(\xi)\}_{,\xi} - [E^2]\{u(\xi)\} = 0 \quad (10)$$

where

$$\begin{aligned} [E^0] &= \int_{-1}^1 [B^1]^T [D][B^1] J d\eta \\ [E^1] &= \int_{-1}^1 [B^2]^T [D][B^1] J d\eta \\ [E^2] &= \int_{-1}^1 [B^2]^T [D][B^2] J d\eta \end{aligned} \quad (11)$$

are independent of $\chi\delta$. The integrals of these $[E^0]$, $[E^1]$, and $[E^2]$ are evaluated using *Gaussian quadrature*. Eq. (10) is a standard ordinary differential equation for the displacements $u(\delta\chi\delta\delta)$ with the dimensionless radial coordinate, $\chi\delta\delta$ as the independent variable.

Solution procedures

By inspection, solution to the set of Euler-Cauchy differential equation represented by Eq. (10) must be of the form as follows.

$$\{u(\xi)\} = c_1 \xi^{-\lambda_1} \phi_1 + c_2 \xi^{-\lambda_2} \phi_2 + c_3 \xi^{-\lambda_3} \phi_3 + \dots \quad (12a)$$

where the exponents λ_i and vectors $\{\phi_i\}$ are interpreted as a radial scaling factor and a displacement modes shapes. The integration constants c_i represent the contribution of each mode to the solution, and are dependent on the boundary conditions.

The displacements for each mode from Eq. (12a) can be written as

$$\{u(\xi, \eta)\} = \xi^{-\lambda} \{\phi\} \quad (12b)$$

Now substituting Eq. (12b) and its derivations into Eq. (10) and then simplifying yields the quadratic eigenproblem.

$$[\lambda^2 [E^0] - \lambda [E^1]^T - [E^1]] - [E^2] \{\phi\} = \{0\} \quad (13)$$

This eigenproblem can be solved using standard techniques, yielding $2n$ displacement modes, where n is the number of nodes used in boundary discretization, and hence is also the size of the coefficient matrices.

Bounded problems can be represented conveniently by taking $0 \leq \chi \leq 1$ (Fig. 1 (a)) and unbounded problems can be represented by taking the range of χ as from 1 to "i.e. $1 \leq \chi < \infty$ " (Fig. 1 (b)). For bounded domain problems, only n modes with negative real component of λ lead to finite displacements at scaling center and for unbounded domain problems those mode with non-negative real component of λ are chosen to enforce finite displacements at infinity. This subset of n nodes is denoted by $[F_1]$ and $[F_2]$ for bounded and unbounded problems respectively. For any set of boundary node displacements, u , the integration constants are as follows

$$\{c\} = [\Phi_i]^{-1} \{u\} \quad \forall \quad i = 1 \& 2 \quad (14)$$

The displacement fields and the stress field can be obtained using the following equation

$$\{u(\xi, \eta)\} = [N(\eta)] \sum_{i=1}^n c_i \xi^{-\lambda_i} \{\phi_i\} \quad (15)$$

$$\{\sigma(\xi, \eta)\} = [D] \sum_{i=1}^n [c_i \xi^{-\lambda_i-1} [-\lambda_i [B^1(\eta)] + [B^2(\eta)]] \{\phi_i\} \quad (16)$$

Eqs. (15) and (16) are, respectively, the semi-analytical solutions for displacement and stress fields.

SBFEM for fracture analysis

Computation of fracture parameters

To compute the fracture parameters i.e. SIFs and T -stress and higher order terms of the crack-tip stress fields, authors has presented two different formulations by comparing the classical linear elastic fields solution (Williams' eigenfunction series) in the vicinity of a crack-tip with scaled boundary finite element stress and displacement fields solution at any point ahead of crack tip in Shrestha & Ohga (2005) and Shrestha & Ohga (2006a) respectively. In these formulations, the so-called 'scaling center' of SBFEM is considered at the crack-tip, as shown in the Fig. 2 and the stress and displacement fields along the radial direction emanating from the crack-tip occurs are analytically calculated to approximate the crack-tip along the line of propagation of the crack. According to Shrestha & Ohga (2005), the mixed mode SIFs, T -stress and higher order terms of the stress fields are computed by the following relations.

Stress intensity factor for mode I

$$K_I = c(\hat{\sigma}_{y'y'})\sqrt{2\pi\hat{r}} \quad (17)$$

Stress intensity factor for mode II

$$K_{II} = c(\hat{\sigma}_{x'y'})\sqrt{2\pi\hat{r}} \quad (18)$$

T -stress

$$T = c(\hat{\sigma}_{x'x'}) \quad (19)$$

and higher order terms

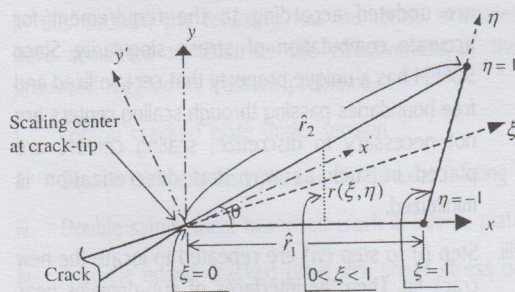


Figure 2. SBFEM element with different coordinates

$$a_n = cA_n \hat{r}^{-n/2-1} \quad \forall n = 1, 2, 3, \dots \quad (20)$$

where $\hat{\sigma}_{x'x'}$, $\hat{\sigma}_{y'y'}$, and $\hat{\sigma}_{x'y'}$ are the stress

components in the direction as shown in Fig. 2, $\hat{r}$ is the radial distance of the boundary node from scaling center, and c is the integration constant. In this paper only the basic equations of the proposed formulation are presented. For a more detailed description we refer to Shrestha & Ohga (2005)

Crack propagation simulation procedures

Several criteria have been proposed to predict the local direction of crack propagation. Among them, one of the most commonly used is based on maximum hoop or principal stress at the crack tip (Erdogan & Sih, 1963). In this study, the maximum principal stress criteria, which predict the direction of crack growth from the stress state prior to the crack extension is considered to crack propagation simulation. In this criterion, it is considered that the crack will propagate from its tip in the direction along which the maximum hoop stress $\tilde{A}$ occurs. The hoop (circumferential) stress in the direction of crack propagation is a principal stress. Therefore, the critical angle, θ_0 , defining the radial direction of propagation can be determined by setting the shear stress $\tilde{A}_r$ to zero.

$$\frac{\partial \sigma_{r\theta}}{\partial \theta_0} = 0 \quad (21)$$

Incorporating first two terms of Williams' eigenfunction series on maximum circumferential stress criteria, the direction of crack propagation, θ_0 , is computed by solving the following equation (Kim & Paliuno, 2003)

$$K_I \sin \theta_0 + K_{II} (3 \cos \theta_0 - 1) - \frac{16}{3} T \sqrt{2\pi r_c} \sin \frac{\theta_0}{2} \cos \theta_0 = 0 \quad (22)$$

where K_I and K_{II} are mixed mode SIFs, and T is T -stress for any instance during the crack-growth. r_c is an additional length scale representing the fracture process zone size. When the values of K_I , K_{II} and T are known, θ_0 can be easily solved by means of Eq. (22). Since the fracture process zone size, r_c is generally assumed to be very small relative to the crack size and specimen dimensions, only SIFs effects are considered to compute the propagation angle θ_0 in this paper

Considering only the singular term, the Eq. (22) becomes

$$K_I \sin \theta_0 + K_{II} (3 \cos \theta_0 - 1) = 0 \quad (23)$$

This leads to the propagation direction in terms of the stress intensity factors

$$\theta_0 = 2 \arctan \left(\frac{1}{4} \left(\frac{K_I}{K_{II}} \pm \sqrt{\left(\frac{K_I}{K_{II}} \right)^2 + 8} \right) \right) \quad (24)$$

This criterion has been widely used because of its simplicity and support by many experimental observations. The application of this criterion can be found from the works by several researchers.

The simulation of crack propagation involves a number of successive analyses. The general flowchart of the proposed crack propagation simulation is presented in Fig.3. Following are some details about the each step of analysis procedures.

- i. In the first step, the initial geometry of the model is read and a SBFEM mesh is generated with sufficient sub-domains according to the requirement for the efficient and accurate crack analysis of a crack structure. In this model, a scaling center should be placed at the crack-tip (Fig. 4 (a)) as a necessary condition of the proposed method for the computation of stress singularity, which occurs near the crack-tip.
- ii. Standard SBFEM analysis is performed to compute the stress and displacement fields ahead the crack tip.
- iii. The fracture parameters: SIFs and T-stress are computed by the proposed formulations (Eqs. (17) to (19)).
- iv. If the crack reaches or crosses any boundary of the geometrical model then the analysis is stopped.
- v. The direction of crack propagation is calculated from Eq. (22) or (23).
- vi. A virtual increment of crack length ("a) is defined according to the user's specifications and the location of new crack-tip is determined from the defined incremental length and computed crack propagation direction.
- vii. By adding two nodes locating on the opposite sides of the crack in the old crack tip (S_1), the sub-

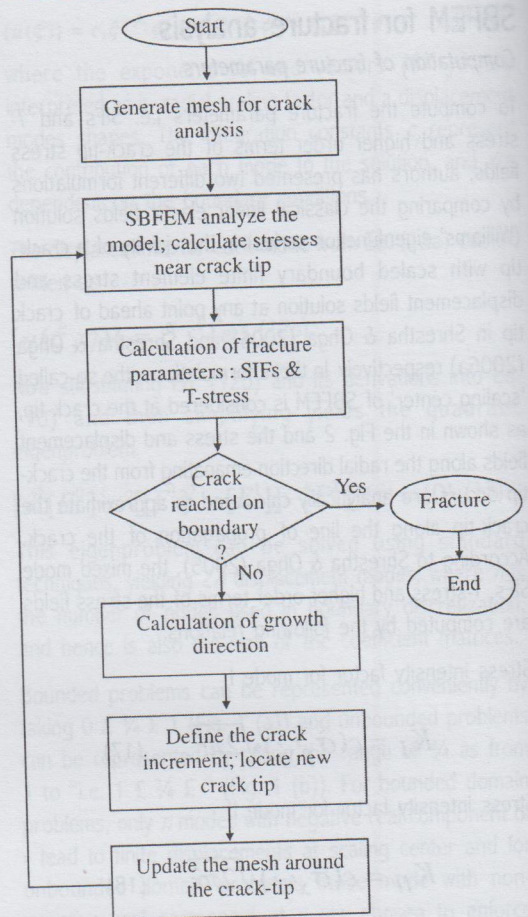


Figure 3. Flowchart of the proposed SBFEM procedure for crack propagation analysis

- domain that includes crack-tip is further sub-divided into three sub-domains as shown in Fig. 4 (b) and then discretization of the boundaries and interfaces are updated according to the requirement for accurate computation of stress singularity. Since SBFEM has a unique property that certain fixed and free boundaries passing through scaling centers are not necessary to discretize, scaling centers are placed in such as way that discretization is minimized.
- viii. Step (i) to step (vi) are repeated to locate the new crack-tip. Then the interfaces of sub-domains near crack are shifted to previous crack-tip as shown in Fig. 4 (c) and upgrade the discretization for analysis.
- ix. Then step (i) to step (vii) are repeated for further simulation.

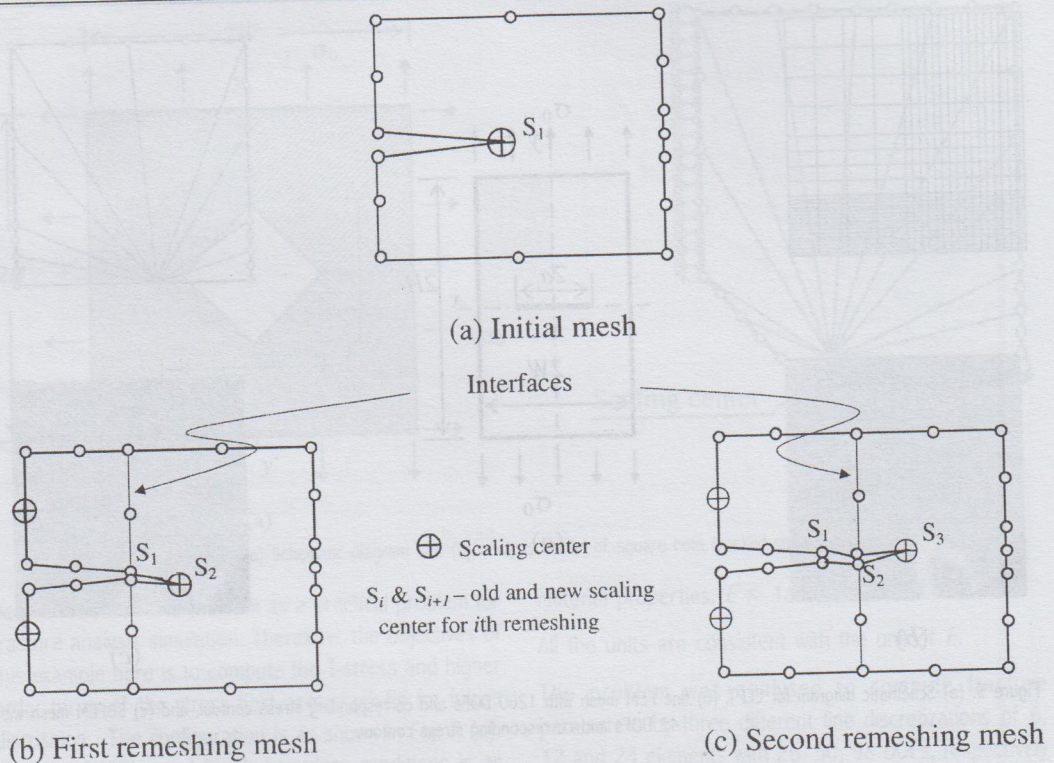


Figure 4. The proposed remeshing procedures

In this procedure, the simulation of crack propagation is carried out incrementally. In every increment, users should be defined the incremental crack length to locate crack-tip. Therefore, the proposed procedure is quasi-automatic.

Numerical Examples

In this section, the following four numerical examples were simulated to illustrate the effectiveness of the proposed method in fracture problems.

- Central cracked plate under tension
- Square hole cracked plate under bi-axial loading
- Double symmetrical branched crack in infinite plate
- A single edged cracked plate with shear stress on the top

The first example was reconsidered to demonstrate the accuracy and efficiency of the proposed method by comparing the stress singularity near crack-tip with FEM

from Shrestha & Ohga (2006a). Second problem, bounded problem with straight cracks, was simulated to compute the fracture parameters i.e. SIFs, T-stress and higher order terms of stress fields and third example was an unbounded crack problem with branched cracks to compute SIFs at branched crack-tips. Finally, a benchmark example for mixed mode crack problems was simulated for crack propagation analysis to demonstrate the effectiveness of the proposed crack propagation simulation procedures. The analyses were carried out using plane strain condition assuming unit thickness for all the problems.

Central cracked plate under tension (CCPT)

A central cracked plate under uniform tension was simulated to compute stress fields near crack-tip. The schematic diagram of the problem is presented in Fig.5 (a), where H and W are plate dimensions and a is the crack length. In this problem, the stress along y -axis, σ_y , ahead of the crack-tip was calculated using Eq. (16).

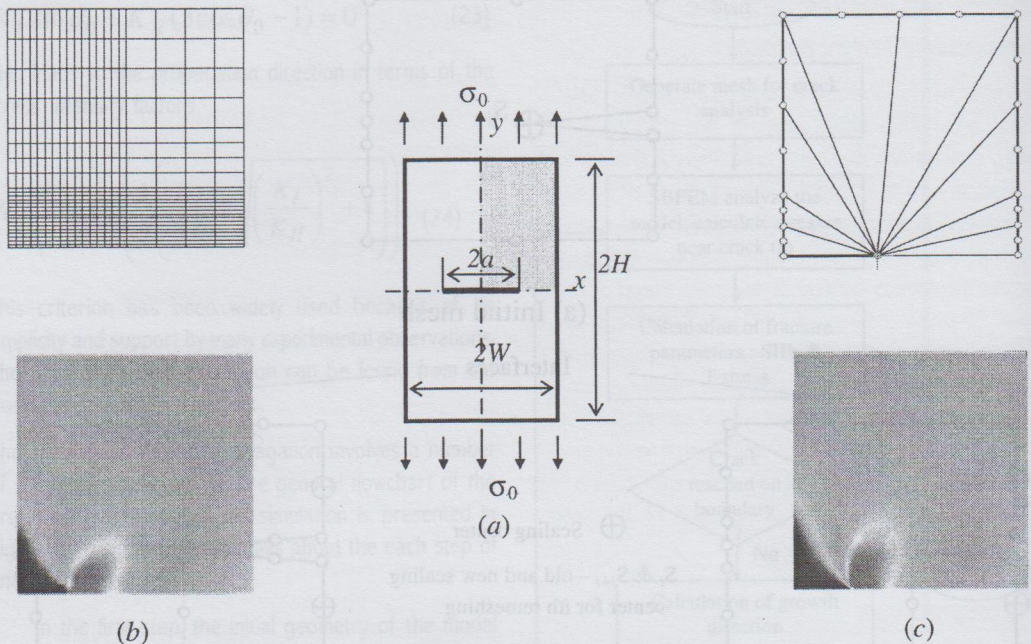


Figure 5. (a) Schematic diagram for CCPT, (b) fine FEM mesh with 1260 DOFs and corresponding stress contour, and (c) SBFEM mesh with 42 DOFs and corresponding stress contour.

The analyses were carried out by both FEM and SBFEM with $H = W = 4$, Young's modulus $E = 1.0$ and Poisson's ratio $\nu = 0.3$. The problem is a biaxial and symmetric, and therefore, only one quadrant (highlighted portion in Fig. 5 a) was modeled. The applied stress was $s_0 = 1$ with its units consistent with that of E . The FEM and SBFEM analysis models are shown in Fig. 5 (b) and (c) respectively. Note that the scaling center i.e., plus sign in the Fig. 5 (c), was placed at the crack-tip in SBFEM mesh. Crack face, which was assumed, as a straight face, and face through the crack-tip were not discretized. The SBFEM analysis was performed with single discretization of 42 degree of freedoms (DOFs) and the FEM analysis was performed with three different discretizations – coarse of 90 DOFs, medium of 366 DOFs and fine of 1024 DOFs. The FEM fine meshes are shown in Fig. 5 (b). Fig. 5 (b) and (c) also presents the contour diagrams of computed stress s_y normalized by applied stress s_0 , s_y/s_0 , of SBFEM with 42 DOFs and FEM with 1260 DOFs. Fig. 6 shows that the comparison of the normalized stress along OX. These contour diagrams and Fig. 6 show that SBFEM results with less than 4 % DOFs of fine mesh FEM results outperforms the fine mesh FEM results.

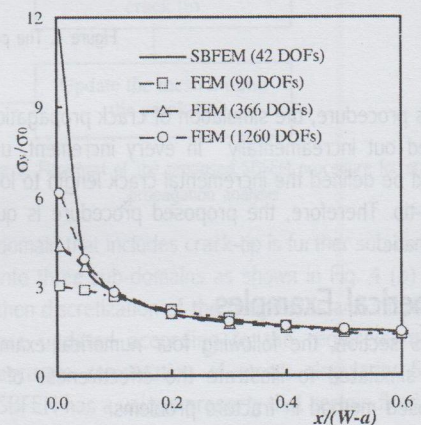


Figure 6. Comparison of normalized stress s_y/s_0 along OX

Square hole cracked plate under bi-axial loading (SHCP)

Second example is a rectangular plate with cracks emanating from a sharp-cornered square hole under biaxial loading in this paper. This problem is reconsidered here from Shrestha & Ohga (2006b) in which only the SIFs have been presented comparing with reference (Yan, 2004) results. Based on the knowledge we have, none of the previous studies have computed the T-stress and higher order terms of this problem although studies has

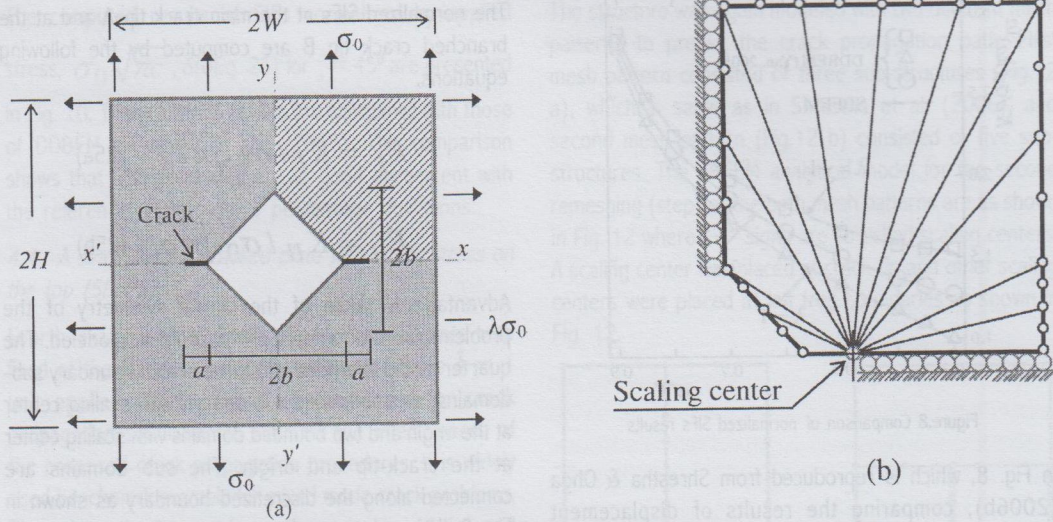


Figure 7. (a) Schematic diagram and (b) analysis model of square hole cracked square plate

been considered this problem as a practical problem for fracture analysis simulation. Therefore, the objectives of this example here is to compute the T-stress and higher order terms of the stress field near crack-tip for future discussion. The configuration is as shown in Fig. 7 (a). A typical SBFEM model with boundary conditions is as shown in Fig. 7 (b) and the parameter used for analysis are as following.

Plate dimension $H = W = 8$,

Dimension of square hole, $b = 1$,

Applied stress, $s_0 \delta = 1$,

Load factor, $\delta l = 0, 1, -1$, and,

Material properties, $E = 1$ and $n = 0.25$.

All the units are consistent with the unit of E .

The problem was analysed to compute fracture parameters by three different fine discretizations of 6, 12 and 24 elements with 26, 50, 98 DOFs, respectively as in Shrestha & Ohga (2006b) for the accuracy of powers values (i.e. 0, 0.5, 1, 1.5 for T-stress, third terms, fourth and fifth terms respectively). The computed results of fine mesh (98 DOFs) are presented in Table 1 for various configurations of crack with three different loading cases. The effectiveness of the proposed formulation to compute SIFs for all the cases is presented

Table 1. Computed T-stress and higher order terms of stress field near crack tip

$(a+b)/W$	$\lambda = 0$				$\lambda = 1$				$\lambda = -1$			
	T-stress	3rd term	4th term	5th term	T-stress	3rd term	4th term	5th term	T-stress	3rd term	4th term	5th term
	a_3	a_4	a_5		a_3	a_4	a_5		a_3	a_4	a_5	
0.3	-0.5378	0.1287	-0.1552	0.0047	-0.3753	0.2750	-0.0605	-0.0565	-0.7002	-0.0176	-0.2499	0.0659
0.35	-0.6625	0.0825	-0.0845	0.0276	-0.3612	0.1919	-0.0014	-0.0330	-0.9638	-0.0269	-0.1675	0.0883
0.4	-0.7720	0.0746	-0.0647	0.0112	-0.3511	0.1616	0.0035	-0.0276	-1.1928	-0.0124	-0.1330	0.0500
0.5	-0.9987	0.0452	-0.0360	-0.0171	-0.3975	0.1121	0.0050	-0.0281	-1.5999	-0.0216	-0.0769	-0.0061
0.6	-1.2439	-0.0110	-0.0135	-0.0451	-0.5319	0.0556	0.0064	-0.0402	-1.9559	-0.0777	-0.0333	-0.0500
0.7	-1.5806	-0.0979	0.0006	-0.0914	-0.8134	-0.0178	0.0018	-0.0728	-2.3477	-0.1779	-0.0007	-0.1099
0.8	-2.2626	-0.2301	-0.0052	-0.2331	-1.4847	-0.1359	-0.0261	-0.1974	-3.0405	-0.3244	0.0157	-0.2689
0.9	-4.5108	-0.5297	-0.0989	-1.2290	-3.8494	-0.3635	-0.1949	-1.1299	-5.1722	-0.6958	-0.0030	-1.3280

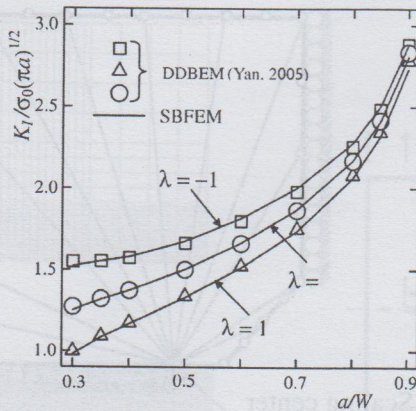
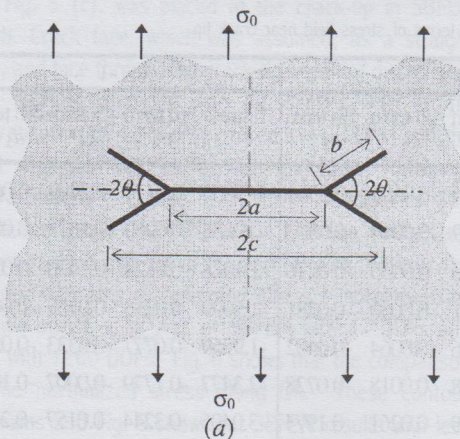


Figure.8 Comparison of normalized SIFs results

in Fig. 8, which is reproduced from Shrestha & Ohga (2006b), comparing the results of displacement discontinuity BEM from Yan (2004). For a more detailed comparison we refer to Shrestha & Ohga (2006b).

A double symmetrical branched crack in infinite plate

Third example, a double symmetrical branched crack (DSBC) problem in an infinite plate with uniform radial tension, is considered as an unbounded domain problem with branches crack. The schematic diagram of the problem is presented in Fig. 9 (a), where H and W are plate dimensions, a and b are the crack length of main crack and branched crack respectively and θ is an angle of branched crack with main crack. The problem was analysed with $W = 20$, $H = 16$, $\theta = 45^\circ$ and $b/a = 1$. The applied load was $\bar{A}_0 = \delta 1$ with its units consistent with that of E .



The normalized SIFs at the main crack tip A and at the branched crack tip B are computed by the following equations.

$$F_I = K_I / \sigma_0 \sqrt{\pi c}, \quad (25a)$$

$$F_{II} = K_{II} / \sigma_0 \sqrt{\pi c} \quad (25b)$$

Advantage is taken of the biaxial symmetry of the problem, and one quarter of the problem modeled. The quarter model is divided into three scaled boundary sub-domains, an unbounded sub-domain with scaling center at the origin and two bounded domains with scaling center at the crack-tip and origin. The sub-domains are connected along the discretized boundary as shown in Fig. 9 (b).

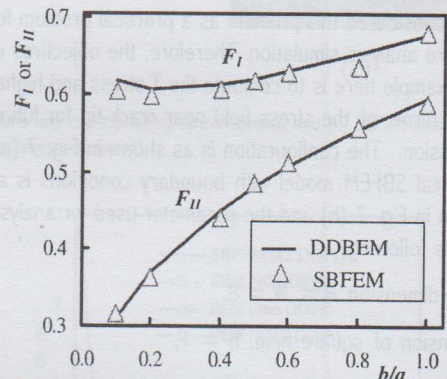


Figure 10. Comparison of normalized SIFs at tips of branched crack for DSBC

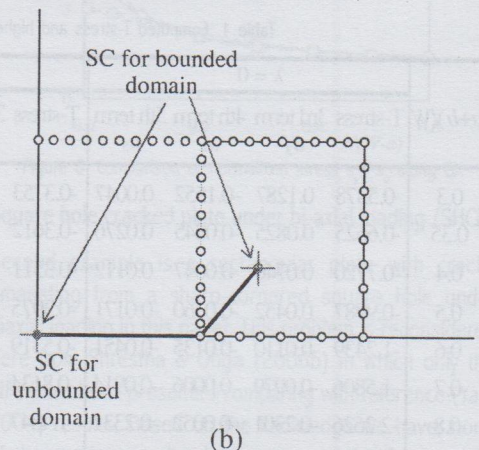


Figure 9. a) Schematic diagrams and b) analytical model of double symmetric branched crack problem

The computed results of SIFs normalized by applied stress, $\sigma_0 \sqrt{\pi c}$, $\delta(\delta \text{Eq. 25})$ for $\theta = 45^\circ$ are presented in Fig. 10. These SBFEM results are compared with those of DDBEM presented in Yan (2005). The comparison shows that SBFEM results are in good agreement with the reference results with 3 percentage deviations.

4.4. A single edged cracked plate with shear stress on the top (SECPS)

Fourth example is a single edged cracked plate with fixed at the bottom and subjected shear stress $\bar{A} = 1$ unit applied on the top. It is considered for crack propagation simulation to examine the effectiveness of the proposed crack propagation procedures. It is widely used benchmark example for mixed mode crack problems. The schematic diagram is as shown in Fig. 11 (a) and other parameters are: $a = 3.5$, $W = 7$ and $L = 16$. Young's modulus $E = 10^5$ and Poisson's ratio $\nu = 0.25$. All units are consistent with that of E .

For the analysis, first whole structure was modeled with single domain placing scaling center at crack-tip and computed the fracture parameters – mixed mode SIFs, T-stress and higher order terms using Eqs. (17) to (20) respectively. The computed results were presented in Table 2. In Table 2., SIFs results are compared with those of Wilson (1969) results from Rao and Rahman (2000) and other results are compared with hybrid crack element (HCE) results of Xaio et al. (2004). For the comparison of T-stress results, the HCE result is calculated by second term, a_2 , results (i.e. T-stress = $4 a_2$) of Xaio et al. (2004). Table 2 shows that the computed results are in good agreement with the literature results with less than 4 percentage deviation.

Table 2. Comparison of fracture parameters for SECPS

Fracture Parameters	SBFEM	HCE Xaio et al. (2004)	Error %
Mode I, K_I	33.95	34.00	0.147
Mode II, K_{II}	4.542	4.550	0.176
T-stress	2.6596	2.6864	1.00
Third term (a_3)	-2.6212	-2.5703	1.98
Fourth term (a_4)	0.2813	0.2724	3.26
Five term (a_5)	-0.2386	-0.2322	2.75

The structure was again modeled with two different mesh patterns to predict the crack propagation path. First mesh pattern consisted of three sub-structures (Fig.12 a), which is same as in Shrestha et al. (2006), and second mesh pattern (Fig.12 b) consisted of five sub-structures. The SBFEM analytical model for the second remeshing (step) of the both mesh patterns are as shown in Fig. 12 where "+" signs are so-called scaling centers. A scaling center was placed at crack-tip and other scaling centers were placed at left free boundaries as shown in Fig. 12.

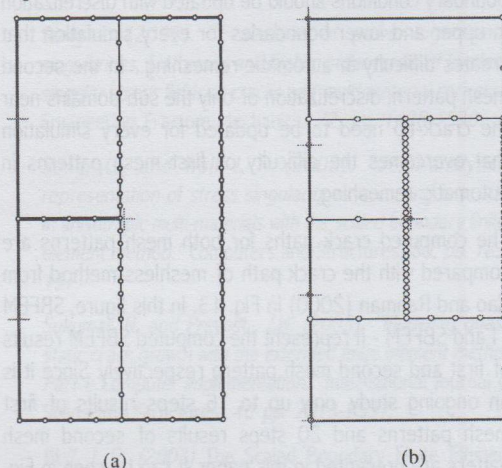


Figure 12. Analytical model of mixed mode crack problem for second remeshing

The crack propagation direction was estimated using Eq. (23) at each increment. The initial propagation angle was -14.75 degree. To compare the computed crack

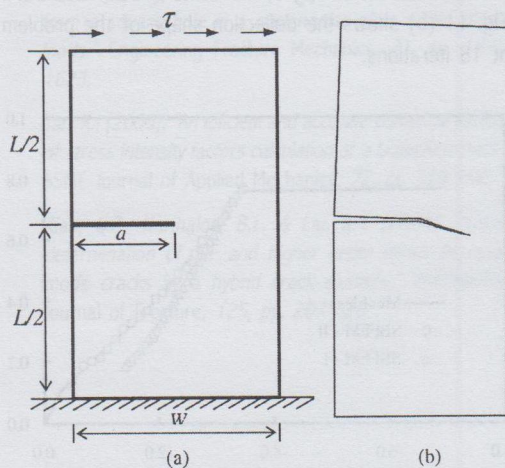


Figure 11. a) Schematic diagrams of SECPS and b) Deflection shape at 18th step of remeshing.

path results, the incremental crack length for each step of crack propagation was considered as 4% of the initial crack length as in Rao and Rahman (2000).

As mentioned in section 3.2, the scaling center that lied in crack tip and interfaces of sub-domains near crack were shifted to the new location of crack-tip and old location of crack-tip respectively and in the old crack tip, two nodes locating on the opposite sides of the crack were added at each step of analysis for both mesh patterns. In first mesh patterns, loading and constrain boundary conditions should be updated with discretization in upper and lower boundaries for every simulation that creates difficulty in automatic remeshing. In the second mesh pattern, discretization of only the sub-domains near the crack-tip need to be updated for every simulation that overcomes the difficulty of first mesh patterns in automatic remeshing.

The computed crack paths for both mesh patterns are compared with the crack path of meshless method from Rao and Rahman (2000) in Fig. 13. In this figure, SBFEM - I and SBFEM - II represent the computed SBFEM results of first and second mesh pattern respectively. Since it is an ongoing study, only up to 16 steps results of first mesh patterns and 20 steps results of second mesh patterns are presented in this paper. It can be seen in Fig. 12 that the present study results of second mesh pattern are in good agreement with these reference results. Fig. 12 (b) clearly shows that the left, top and bottom boundaries and ahead of crack-tip portion of the structure are not necessary to discretize that leads to minimize the remeshing burdensome of FEM and BEM. Fig. 11 (b) shows the deflection shape of the problem at 18 iterations.

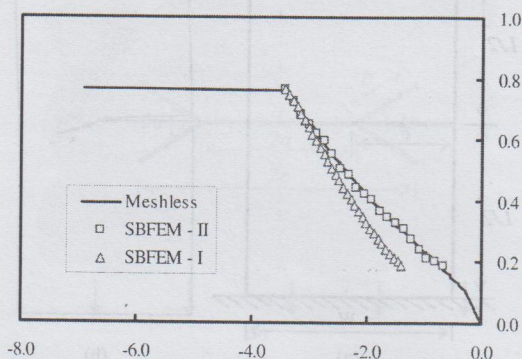


Figure 13. Comparison of crack propagation trajectory

Conclusion

In this paper, recently developed boundary finite element method named scaled boundary finite element method has been applied for fracture analysis. Three numerical examples both bounded with straight cracks and unbounded with branched cracks demonstrate accuracy and efficiency of the proposed method to compute the stress singularity and fracture parameters i.e. SIFs, T-stress and higher order terms of crack-tip stress fields. In addition, using advantages of SBFEM over traditional FEM and BEM such as discretization of only the domain boundaries and interfaces of sub-domains, no need to discretize certain fixed and free boundaries, and freedom in sub-structuring and locations of scaling centers, a quasi-automatic procedure of the proposed method has been presented for crack propagation simulation based on linear elastic fracture mechanics. A mixed mode crack problem has been examined with two different mesh patterns. It can be seen that the numerical results obtained from the SBFEM simulations are in remarkable agreement with the corresponding ones in the literature. Based on the results of the study it can be confirmed that the proposed numerical method can be applied to crack problems more easily with relatively simple remeshing model than other computational methods for crack propagation analysis.

This paper has dealt with a benchmark problem for crack propagation simulation considering only the SIFs effects. It can be applied to simulate problems with more complex problems considering both SIFs and T-stress effects. On the other hand, even though SBFEM has many advantages for fracture analysis over traditional FEM and BEM, FEM is very versatile to model complex problems. Therefore, coupling of SBFEM with FEM will be more effective for fracture analysis which is expected to appear in the authors' forthcoming publication.

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COMPARING NEPALESE AND WESTERN MEDIEVAL CITIES,

A Case Study of Kirtipur

Vijay Burathoki*

Introduction

Although separated by vast distances and following separate evolutionary paths, it is quite interesting to note that the development patterns of western and Nepalese society, especially with regard to the form of the medieval cities, is not all that different. On closer scrutiny we find that the form of the medieval city and its urban spaces in both cultures were greatly determined by the overriding need for protection against invading forces, the dominant role of religion in the daily lives of the people and the importance of trade in the revival of the society.

Due to the constant warfare, fortified cities first appeared on the plains of Mesopotamia, raised on artificial mounds. Thereafter, Mycenaean and Greek cities, which also were constantly at war among themselves, were built on natural high ground and enclosed by walls. The Roman cities during the heyday of the empire did not need fortification although new outposts in the frontiers were built as formal layouts within protective walls. With the fall of the Roman Empire and the turmoil which followed during the medieval period, topographical considerations and fortifications became the most important factor in the establishment and growth of cities.

This article tries to compare the development patterns of western and Nepalese medieval cities, especially the fortified hilltop cities which emerged during the Dark Ages. In the Nepalese context, Kirtipur has been selected for a more detailed analysis of its urban structure since among the cities of the valley, it more closely resembles the hilltop fortified cities of the West and also because, in spite of the proliferation of modern construction, much of the streets and squares of the core area of the city has not been altered by later developments and displays its ancient form. A more accurate and comprehensive comparison could have been obtained if additional Nepalese examples of similar medieval hilltop cities could have been included, such as Pharping and Thimi. However, due to time constraints and limitation of scope, this will have to be left to future scholars.

* Professor and Head of Department, Department of Architecture, nec, e-mail: vijay_burathoki@yahoo.com

Historical Perspective

Western civilization went into decline after the fall of the Roman Empire during the 5th century. After declaring Christianity the state religion and actively promoting it, Constantine shifted his capital to Byzantium in 330 AD which left Rome and the western part of the empire vulnerable to barbarian invasions. The fall of the western empire was not a single cataclysmic event, but a gradual process as barbarians from the north continued to gnaw away at a decadent empire beginning from the third century which lasted for almost a millenium. There were several attempts to consolidate and reorganize the state during the 6th century by Justinian and the 9th century by Charlemange but they were unable to stop the decline. Rome did not need any fortifications during the period of Pax Romana. Its highways extended all over south-central Europe and the Mediterranean region. But with the onslaught of the barbarians, the highways and the absence of fortifications became a liability. People fled the cities as all forms of organized governance and infrastructure disintegrated. The great cities saw a drastic reduction in their population. The people took to the hills away from the cities and the major highways to escape the plunder and slaughter.

By the 4th century monasticism, which had its roots in Eastern culture, had already reached the West. Partly due to fear of persecution as well as the search for a secluded ascetic life, monasteries had been set up in strategic isolated locations, often under the protection of a castle. With their progressive programs, these monasteries drew adherents to Christianity and became magnets for people seeking shelter from the mayhem. Medieval cities grew around these monasteries and castles, encircled by fortification walls and moats. The darkest periods were between the 8-11th century when violence and terror were spread by the Vikings and the Saracens. Protection became the first priority and cities were built on hillocks or bends in the rivers surrounded by strong fortifications. Life in the countryside became less attractive as compared to the secured life in the protected cities.

During the period of great upheaval in the western civilization, Nepal was going through a period of relative peace and stability under the Lichchavis. Protective walls around cities were not felt necessary (Tiwari, 2001). It is only after 879 AD that Nepal entered the Dark Ages

which lasted through the early period of Malla rule till about 1367 until the rise of Jayasthitimalla, an astute and powerful Malla king who consolidated the empire. During the Dark Ages there are no records of violent regime changes. It appears, without strong central rule, the Lichchavi empire gradually broke up into many petty and weak kingdoms or city states which suffered many raids. Although the pillage and terror was less sustained than what was faced by the Western society, Nepal, nevertheless, faced significant destruction on a regular basis. Mithila kings frequently made violent raids into the Valley between 1097-1311 AD which stopped only after their kingdom was destroyed by the Muslims. Between 1287-1328 AD Khasas attacked the Valley more than half a dozen times but unlike the Mithilas they spared the holy sites. Mukunda Sen of Palpa is said to have ransacked the Valley sometime in the mid 13th century while Muslims from Bengal devastated the Valley in 1349 AD. Because of the constant attacks, it became necessary to build protective walls around cities. Hilltops and *tar* locations were ideal not only as defensible positions but also to conserve prime agricultural land.

Jayasthitimalla consolidated power and brought stability to the Valley, however, within a century his kingdom was broken up into three city states by the sons of Yakshamalla. The constant feuding among brothers once again brought instability and terror to the country, requiring cities to build and remain within fortified walls. It was only after king Prithvi Narayan Shah conquered the Valley in 1769 and considered the whole valley to be a fortress that fortifications became redundant and the walls and the city gates were allowed to disintegrate (Slusser, 1982).

The Origins of Kirtipur

The *Vamsavalis* report that Emperor Ashoka came to the Valley in mid-3rd century BCE and built the Chilancho stupa of Kirtipur along with the four stupas on the outskirts of Patan. This is hard to prove, as there are no records of Ashoka's visit to Nepal. Padmagiri chronicles indicate Raja Sadasivadeva established Kirtipur. Another chronicle suggests 914 AD as its date of establishment while Levi believes the establishment date to be sometime during the 12th century (Shokoohy et al, 1994). The *Gopalarajavamsavali* refers to the town as *Gunde Kwatha* or forest town fortress and tells about an attack by Kitapala of Patan in 1242 AD. The main deity of the

town, Bagh Bhairav is referred to as *Gundethanadhipati*. Nirish Nepal postulates a date that goes back more than a millenium. He believes that the seven villages of Kathmandu Valley around Machhegaun, including Kirtipur, were inhabited by the Gopals and the Mahispalas. The festival of *Satgaon*, which is continued to this day, is believed to be a relic from the earlier times when the guardian goddesses of the seven villages were brought together to the temple of the mother goddess of Vishandevi on the banks of Balkhu at Naikap (Nepal as quoted by Tiwari, 2001). The temple of Indrayani of Kirtipur, one of the seven goddesses, is situated just outside the northern *Dya Dhoka* (gate of God), one of the two existent historic gateways of the city. The very early existence of the temple and its association with Kirtipur is a strong indication of the antiquity of the city itself.

During the Lichchavi period, Sthitidrangga accommodated all the villages of *Satgaon*. In later period, the military outpost of Shitatilma which was located at Kisipidi may have been shifted to the hillock of Kirtipur which was built as a fortified city by the end of the first millenium AD (Tiwari, 2001). Initially it functioned as a satellite to both Patan and Kathmandu but in the later Malla period it was the principality of Kathmandu. Religious landmarks and rituals could have been the major determinants of the plan of Kirtipur whereby specific gods are allotted specific nodes as per ancient planning doctrines (Herdick as quoted by Tiwari, 2001).

Bagh Bhairav, the predominant Hindu temple of Kirtipur, is referred to as *Gunde* or *Jhawa Dya*, indicating its pre-Lichchavi origins but its current name can be dated to the time of the setting up of the city (Tiwari, 1989). The first historical record related to Bagh Bhairav is an inscription dated NS 635 (1515 AD) about the renovation of the temple by Jagat Pal Varma, a *mahapatra* of Patan (Shokoohy et al, 1994). This is proof that the temple was in existence long before that time. There are many images of gods in temple shrines located within the Bagh Bhairav complex which are datable to the Lichchavi period, suggesting that the temple and the town of Kirtipur could at least date from that period.

Buddhist legends claim Chilancho chaitya, the preeminent Buddhist stupa of Kirtipur, to be among the set of stupas older than the Patan stupas (Herdick as quoted by Tiwari, 2001). Most of the images and structures of Chilancho

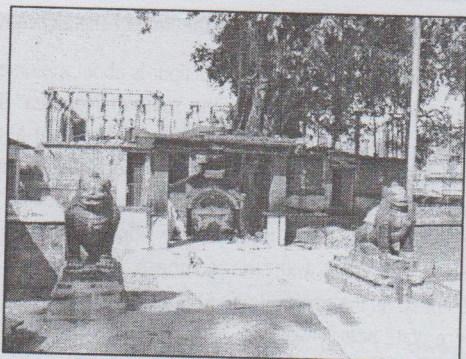
can be dated to the 17th century but the current structure is a result of continuous renovations, which has erased its original form. The stupa could be much older. The earliest records show Jagat Pal Varma, who also renovated Bagh Bhairav, made repairs in 1533 AD (Locke, 1985). Five of the eight monasteries of Kirtipur are in the immediate vicinity of Chilancho while the remaining three are close by in the Buddhist area of the town. Some of the bronze sculptures of the viharas date from the 6-7th century AD. These have been removed to the National Museum for security reasons (Shokoovv et al, 1994). Thus it can be surmised that while the major religious structures can trace their origins to a period much before the historical date of establishment of the city, the city could have been in existence as an unfortified settlement long before recorded history. Just like the western medieval cities which grew around monasteries, the city of Kirtipur could have slowly grown around the important Hindu and Buddhists sites and evolved as a fortified city once the period of foreign invasions began.

The fortification walls, which were definitely in existence by the medieval period, were constructed of bricks and were about 80 cm thick at the base. The walls encircled the entire city built on the upper part of the hillock which does not include Khasi Bazaar and Bahiri Gaon and is said to have 12 gates (Shokoohy, 1994). Of the original gates, the northernmost gate of *Dya Dhoka* displays its original form while *Samal Dhoka* which lies a few hundred meters to the south of *Dya Dhoka* has been reconstructed recently in a similar design form. The corbelled opening and sloping roof of *Dya Dhoka* strongly resembles the palace gate of Thimi illustrated by Korn (Korn, 1976),

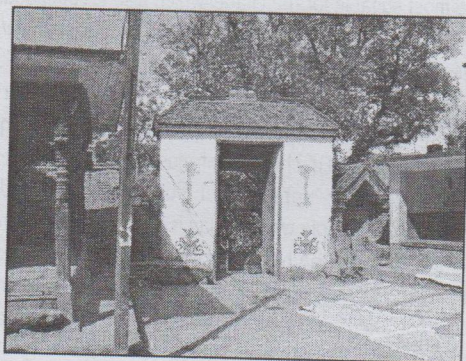


Fortification walls of Kirtipur

Source: Kirtipur, An Urban Community in Nepal, 1994



The Shrine of Indrayani



Dya Dhoka

but without its resting platforms, and could probably be from the same period.

During the time of the siege by King Prithvi Narayan Shah, Kirtipur was a principality of Kathmandu and acted as the main bulwark against the Gorkhali attack. After many attempts, the Gorkhalis were able to subjugate the city in 1767, more by treachery than physical assault. The fortifications must have been very strong to withstand such continuous attacks. More than a century later Oldfield still found much of the city in ruins which was confirmed by Levi in the early 20th century. Oldfield's estimate of the town's population was less than 5000 while Levi's estimate was 4000. The 2001 census put the population as 40835. Although it is difficult to predict what percentage of this population resides within the old city, what is certain is that the major growth has taken place in the newly developing areas at the base of the hillock and not in the old town area.

With the loss of its function as a fortress town overlooking the major trade routes from the south and the west, its trade activities suffered heavily. Even its agricultural base was eroded when the Tribhuvan University acquired most of its fields. Although Kirtipur has seen massive physical

growth in recent times, fortunately this has occurred mainly along the base of the hillock, leaving the hilltop settlement more or less intact. The building stock of the old settlement is rapidly being replaced by modern structures, however, the difficult topography and congestion has discouraged attempts to make any large scale changes to the city streets and squares.

Determinants of the Western City Form

For protection, hilly sites were chosen in Europe to establish villages and cities, which grew in slow stages around a castle or a monastery, closely following the topography and changing gradually over generations. Castles and churches occupied the highest points of the hillocks. Because of the hilly nature, medieval plans were informal rather than regular. Winding streets followed the contours providing a blocked but ever changing vista (Mumford, 1961). The central core was surrounded by a series of irregular rings, which had the effect of enclosing and protecting the center. The town gates were the meeting points between the urban and the rural world and were the most appropriate location for customs house, immigration control, inns and taverns (Mumford, 1961). Craftsmen and merchants usually set up shops in the adjoining streets.

Dominant medieval buildings did not have formal axial approaches. By the medieval period the Church had become the dominant institution and the church building occupied the central location, although this may not necessarily be geometrically central. Because of its regular use, the market came to be located close to the church. Market squares were of irregular shape. Often the streets widened to accommodate the market and provide a space big enough for public stalls, gatherings and ceremonies. The cathedrals and town halls had mass and height commensurate with their symbolic values, otherwise, the rest of the town was kept at human scale. As trade once again became a major economic activity, the market squares became important elements of the town.

As towns grew larger, small sectors with their own churches were added but without the loss of scale. Wheeled traffic was secondary and traffic streets were often distinguished as the main traffic street and lesser street. The winding streets were designed to provide a perception of a much larger town as well as confuse the attackers. Medieval towns generally did not extend beyond a half-mile radius. Expansion occurred by extending the

walls. Walls disappeared only after gunpowder and development of accurate cannon made these redundant.

As religion grew more dominant and became the main unifying force, its structures slowly became more grand. Every city had a church and its spires were the first to be seen when approaching the city. The church provided vital social services through hospitals, almshouses, schools, hospices etc. These neighborhood centers were the focus of daily community life. To sustain the church system, the community donated one tenth of its annual income, which was supplemented by voluntary donations.

The city provided the stage for the ceremonies of the church. The streets and urban spaces were mainly designed for the great religious processions and the final ceremony at the church (Mumford, 1961). The towers of the church and the campaniles, which were at least partially visible from any part of the city, towered above the other buildings providing a focal point to the city. Approaches were kept short and the vistas were blocked to accentuate the effect of verticality. Narrow streets providing limited view would dramatically release the constriction in a plaza or a market place. The images of Jesus, Mary or saints would be carried through the streets during the procession.

To survive during the medieval times, one had to be associated to a manor, a monastery or a guild. Group protection was the most assured means of survival. After the church the guild was the most important association. It began in England in the 9th century as a religious fraternity which was set up to protect its members against accidents in life and providing a decent burial. After the 11th century relative calm prevailed leading to a spurt in economic activity. This led to the growth of merchant and craft guilds which helped to once again revive trade as a major economic activity.

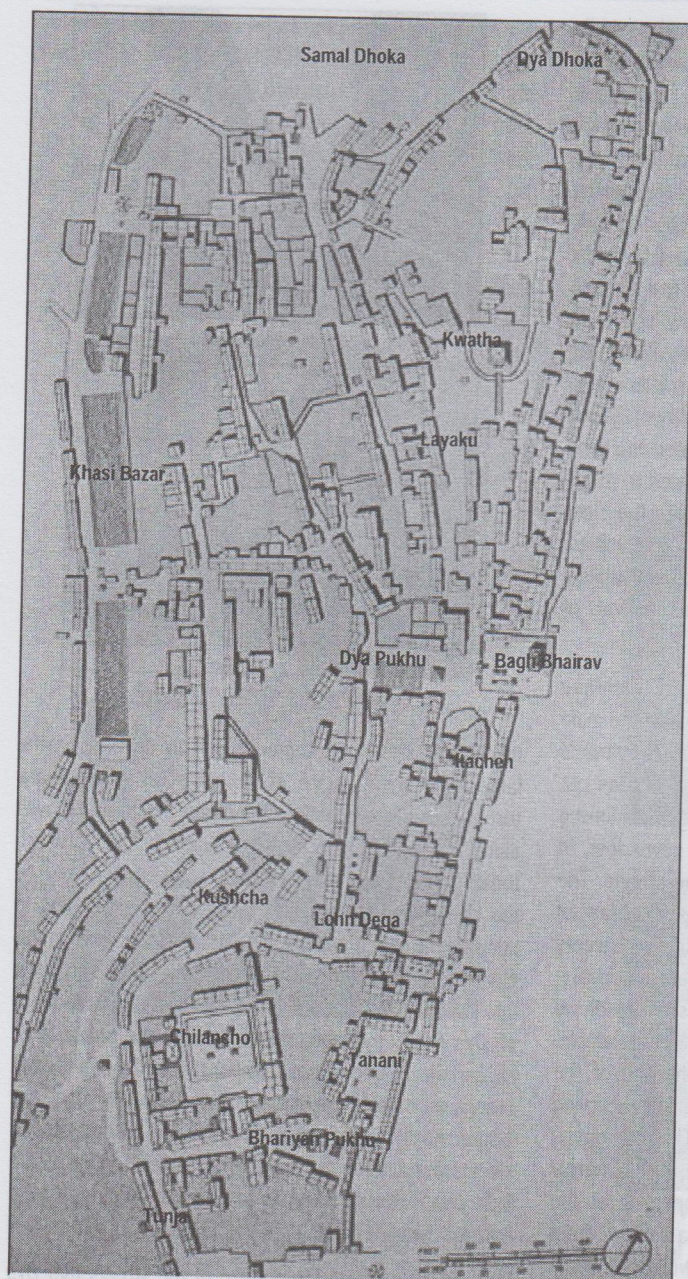
Analysis of Kirtipur's Urban Form

Just as the need for protection forced the medieval cities of the West to choose hills that overlooked the surrounding fields and controlled major trading routes, the wooded hill of Kirtipur must have been an ideal site for a fortified city since it overlooked the rich agricultural plains along the Bagmati and Balkhu rivers. Its strategic location also allowed it to control the important trade routes from the south and west leading to the three main cities of the Valley and further on to Tibet which

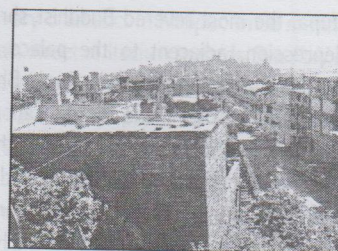
had been in use since at least the time of the Lichchavis.

The narrow ridge of the hill of Kirtipur is about a kilometer long and about 80m above the surrounding area. It is roughly aligned towards NW-SE. It is relatively flat at the top with two distinct mounds at the northern and southern ends and a saddle in the middle. The shorter side of the ridge is roughly 200m in width. The slope becomes quite sharp after that with the northern slope being the steepest. As the name *Gunde Kwatha* suggests, the slopes were quite heavily wooded. The northern mound was the highest point and, just as in the western cities, this was the most suitable for the citadel which also accommodated the royal quarters. This area is still referred to as *Kwatha*, which means fortress. The citadel design of the palace is very different from the Malla palaces but similar to Indian tradition, suggesting its much earlier origins (Shokoohy, 1994). The citadel must have been built on two levels, the upper level surrounding the Uma Maheshwore temple which today is just below the highest point of the hill, the highest point being left for the royal clan goddess of Taleju (Tiwari, 1989). Its extension must have occupied the lower terrace which today is referred to as *Layaku* or palace.

The space in front of the palace is a wide street rather than the large plazas seen in the bigger Malla towns. The palace of Thimi, which resembles Kirtipur in many ways, also does not have such a plaza. The constricted space in front of Thimi's palace, its central location and the existent gate suggest it too may have been of citadel design. For a square occupying the foremost position in the hierarchy of urban spaces to be of such modest scale, this must have been more of a compulsion due to the topography. The palace square of Kirtipur also lacks the temples, shrines and rest houses that are so plentiful in the palace squares of Kathmandu, Patan and Bhaktapur. This may partly be due to the restricted space. In the larger cities whose coffers were full due to the lucrative trade with India and Tibet, generations of kings kept on adding temples to their squares in commemoration of important events. The kings of Kirtipur who must have been subservient to Patan and Kathmandu may not have had such resources at their disposal. The palace squares of Kathmandu and Patan lie at the crossroads while Bhaktapur's straddles the main trading routes. In Kirtipur the palace square appears to come to a dead end since the major streets leading to the gates and out of the city deviate from *Dya Pukhu* and do not



Source: The Physical Development Plan for the Kathmandu Valley, 1969



Looking south from Kwatha to Chilancho



Layaku square



Bagh Bhairav temple



Chilancho stupa

pass through the palace square. Although today there is a narrow lane between the upper terrace and *Layaku*, this may not have been there during earlier times when the citadel occupied the whole hillock and the lower terrace.

In the western medieval cities where religion was the dominant force, the church also occupied a prominent location either close by or set along an axis with the citadel. In Kirtipur we see a similar set-up. The southern mound which was quite prominent and clearly visible from the citadel was chosen as the site for the Chilancho

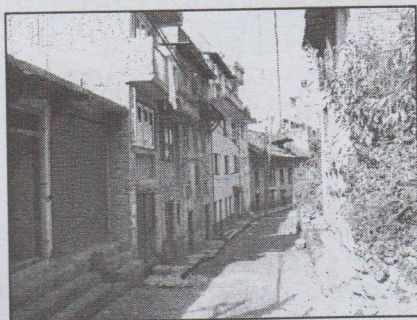
stupa, the most revered Buddhist shrine. In the middle depression, adjacent to the palace, was located the dominant Hindu temple of Bagh Bhairav. Two major streets connected these three locations, converging on the main palace street. In Kirtipur the location of the Buddhist shrine in the southern mound, apart from giving it status and symbolic value comparable to its Hindu counterpart, helped to segregate the Hindu and Buddhist communities. The king, being a Hindu, remained close to the main Hindu shrine and was surrounded by high caste Hindus (Shokoohy, 1994). The high caste Buddhists congregated around the Chilanco area. The intervening areas were occupied by the farming community of Jyapus who were Buddhist but who also participated in Hindu festivals while the untouchables were relegated to areas outside the city walls near the gates. Despite the clear separation of the two dominant religious communities, there was no enmity among them and both communities participated vigorously in the many religious festivals of the city.

As in the western examples topography, defense requirements and religious activities have been the main determinants of the urban form of Kirtipur. The streets follow the contours, curving, rising and dipping as per the landform, however, the general axial alignment linking the three major elements of the city is never lost, in spite of the many curves and bends in the streets. The curved streets, blocked vistas, shifting axis, the burst of open spaces at the nodes from constricted streets designed to confuse enemies as well as create anticipation used as urban design elements by the western medieval cities is used with similar effect in Kirtipur. For example, one of the spinal streets begins from the site of the original south gate at Tunja, moves along in short curving segments following the contour line to Thatujal, opens up at Kushcha, a large community space, turns sharply north along a constricted segment to open up at the temple square of Lohn Dega. Further on a narrow street leads to the other major spinal street while the north west street opens up in the square of Guta Paun and continues on in narrow shifting and curving segments to the southern corner of the central square of *Dya Pukhu*. No important element of the *Dya Pukhu* is visible from the street until one is actually inside the square.

The other spinal street begins from the narrow street of Dhaksi, which is located at the gate just to the north of the south gate. It opens up at Bhariyan Pukhu, goes



Shifting axis at Tunja

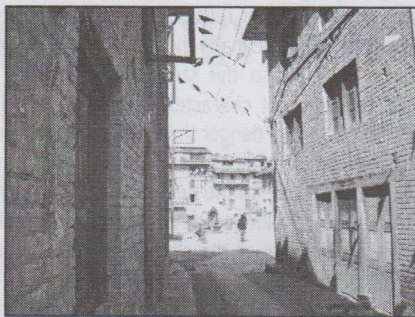


Street following contour at Thatujal

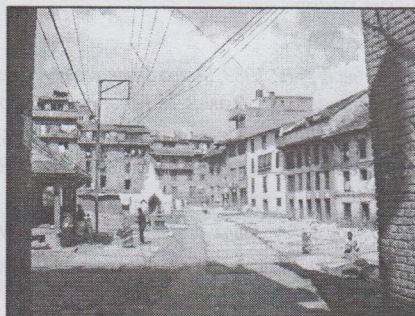
through a constricted segment only to open up in the large community square of Tanani. After a few sharp turns within narrow confines the street widens and moves along a relatively long stretch known as Itachen which today provides the only vehicular access to the city. As the street approaches *Dya Pukhu*, the street begins to curve, thereby blocking the vista. Again the major elements of the square are completely hidden and burst into view only upon entering the square. From the square of *Dya Pukhu* the main street leads to the palace area of *Layaku*. A side street parallel to the *Layaku* follows the lower contour on the north side to arrive at the historic northern gate of *Dya Dhoka*. Two roughly parallel streets descend to the lower level on the southern side from *Dya Pukhu* and *Layaku* to arrive at another historic gate of *Samal Dhoka*.

One can notice from the pattern of the streets that *Dya Pukhu* square is the central space of the town and hierarchically the most important as it serves the main deity of the city, Bagh Bhairav. It also functions as the main market just as the central market squares of the West. A relatively large *pukhu* or pond occupies a significant portion of the southern part of the square. The railing around the pond is of recent construction and forms a visual and physical obstruction. Earlier it

must have been edged with bricks or stone boulders as in many ponds of similar settlements of the Valley, which would have made it less obtrusive. The location of the pond in the main square where it causes constriction and obstruction in holding festivals would not have been logical. However, this probably underscores the importance of a water reservoir for a hilltop fortress city during times of siege, since many of the natural springs and ponds at the base of the hill would have been outside the walls.



Entry to Tanani from south

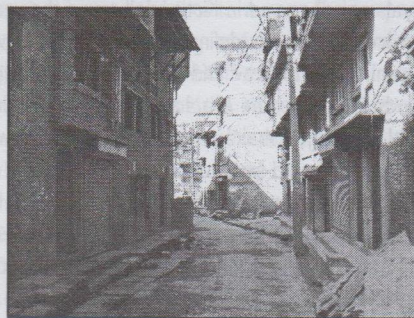


Drying grains in Tanani

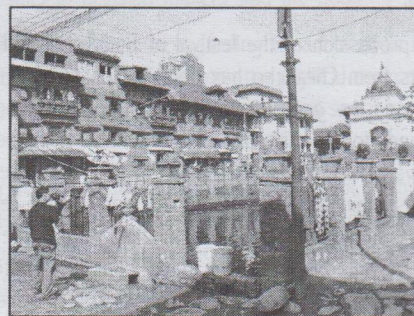
Almost equal in size to these nodal temple squares are several *nanis* or community squares such as Tanani, meaning a large open space, Kushcha etc. which appear as a sudden widening of the street. These squares are also vibrant urban spaces as many household activities and religious festivals are held here. These squares provide the space to dry grains, hold festivals, and serve as a playground for children.

A major difference in the design of the larger squares is that in Nepal, particularly in the market squares, the focal elements are always hidden from the streets (Tiwari, 1989), whereas in the West, a portion of the main structure is always visible as a beacon to the approaching person. In Nepal the element of surprise upon entering a square and being overwhelmed by the architectural

elements is often very dramatic. In Kirtipur, while moving north along the main street of Itachen towards *Dya Pukhu*, the central square in front of Bagh Bhairav temple, one is completely unaware of the presence of the temple, the *dabali* or the secondary Narayan temple which was originally a three tiered temple but was rebuilt by Bhim Sumsher in its current dome form after it was destroyed during the earthquake of 1833. Only upon entering the square and glancing sideways is one overwhelmed by the scale and architecture of the Bagh Bhairav temple. The original Narayan temple must have been a worthy counterpoint to the Bagh Bhairav temple. Unfortunately, today it is a small whitewashed and domed nondescript structure whose architecture and scale fails to generate much drama.



Entry to Dya Pukhu from Itachen



Dya Pukhu square from south corner

The element of surprise is also found in the other squares although the effect is not always as dramatic. Even the Uma-Maheswore temple, which towers above the Kirtipur skyline because of its location on the highest mound, is only partially visible from the *Layaku* square. Only after turning sharply at the historic *Singha Satta* at the end of the square and again turning to face the stairway is one confronted by the soaring structure of the temple and its high plinth. Similarly, the Chilanchu stupa is set back from the Sinduwal street and gives no indication of

its presence. Only upon looking through its outer gate does one get a glimpse of it framed by its inner door.

Religious festivals were the main events of a town during medieval times both in the West and in Nepal. People congregated in the squares in front of the temples and took out processions along the major streets. Images of the gods were carried in chariots and hand-held palanquins. The main streets were wider to accommodate the mass of people and the chariots. In Kirtipur the gods were carried in *khats* so the streets were sloped rather than stepped. The major streets connected the main temples and gods rested in some of the larger squares during their journey around the city. The durbar square was inevitably a part of these festivities.

Festivals are observed in Kirtipur all round the year and the processions follow defined paths. In the festivals of Indrayani, Bagh Bhairav and Krishna Astami, images of the gods are carried on *khats* around the city. During the festival of Bagh Bhairav the procession follows the alignment of the old fortification walls and in the evening the people circumambulate the temple. That may be the reason why a space almost as big as the central square has been reserved inside the temple precincts. Interestingly, the Chilanchi stupa also has a large space around the shrine as circumambulation is an important ritual.

The procession of the festival of Buddha Jayanti which starts from Chilanchi has been discontinued in recent years as the *guthi* responsible for the celebrations lost its lands to the university and was unable to support the festival. The *guthi* is quite similar to the guild system and it was mainly responsible for supporting the religious and community activities. Unfortunately, many of the *guthis* are slowly dying out or have completely stopped functioning, leading to a gradual decay in services and deterioration of public and religious structures. Nonetheless, it can be observed that in Kirtipur the alignment of streets, the location of squares and the placement of structures are all intricately linked to the intimate relation between man and God.

Epilogue

Western countries have declared many of their medieval cities as national heritages and are making great efforts to conserve them. Unfortunately, Nepal has yet to recognize the importance of conserving our ancient cities and cultural practices. Today, Kirtipur is under great

pressure to modernize and the process of change has already begun. Ugly modern structures have begun to replace the old and crumbling traditional buildings. While referring to the city map of Kirtipur of 1969, a gradual process of infill construction can be observed which is bound to gain momentum in the future. A blacktop road has made its way into the main street of Itachen and heavy vehicles can be seen occasionally trying to negotiate the narrow streets. Small vehicles can be found parked all over the town, even in the remote interior squares. So far, the fixed alignment of the streets and squares in relation to the inviolate religious structures as well as the difficult terrain have made the widening or realignment of streets difficult, so the streets and squares have retained their ancient character. In the not too distant future, there is a real danger that with growing economic activity and loss of religious and cultural practices, which is already evident due to the decline of the *guthi* system, the streets will be widened to enable larger vehicles to serve the inner parts of the city. Then the whole urban fabric will be altered and a cultural heritage will have been lost forever. It will be difficult to ascertain whether Kirtipur ever had its roots in the medieval period.

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ENVIRONMENTAL IMPACT ANALYSIS VIS -A- VIS PROJECT PLANNING & URBAN DEVELOPMENT

Bharat Sharma*

"Environmental Impact Analysis" is very useful tool to assess likely impacts to be generated by any project. In project planning and in urban development context these days ENVIRONMENTAL IMPACT ANALYSIS is not a new feature of planning in most of the developed countries of the world. In fact even the developing countries have gradually started to use environmental impact analysis as a very effective "Yard Stick" to measure pros and cons of any development project formulation. The prime objective is to identify all potential impacts of a proposal with respect to HUMAN INTERFERENCES with natural as well as social settings and to disclose fully its implications to decision makers and to the public. Consequently this has led to the developments of the methods which can be used not only to identify, describe and assess the impacts of a proposal, but also to communicate the results to decision makers and the public.

One pertinent observation of great importance regarding impact analysis is the suggestion that it should not be confined to effects upon the physical environment (though of prime importance) and should include economic and social impacts, too.

"The cost benefit analysis" or the apparently tangible gain should not be the only guiding tool and criteria in decision maker's mind for any development project appraisal. One should go beyond to evaluate the project proposal in wider perspective so as to mitigate the hidden negative aspects (visual social and environmental) of the so called "Feasible Project". If we analyse purely on economic aspect only it is very likely to be lopsided decision, on our part.

The employment opportunity which a development project is likely to generate (Construction & allied) is often regarded as a benefit to the local community, and perhaps some projects could have go further to save scarce foreign exchange by import curtailment of some particular commodity. But this is not all, what about the SOCIAL, CULTURAL, HEALTH and above all the ENVIRONMENTAL-- COSTS which a project is very likely to incur if we happen to verlook these aspects ? Could we be candid enough to admit that we have glaring examples

* Professor, Department of Architecture, nec. The author is an environmental planner an architect.

of projects like cement factory— Chobhar, tannery factory— Bansbari, couple of brick factories, slashing and burning of forest for settlements and whole lot of urban development & design works where we have brushed aside the environmental aspects and have faced consequential negative impacts of aforesaid projects in the scenic Kathmandu Valley to an extent of spoiling INTRINSIC QUALITY. Sure enough these projects have some positive aspects in our balance sheet too. But does not the environmental pollution, visual & otherwise far outweigh the economic gains, we are supposed to make? Rationally we should work out the "Trade-Off ". I feel this is where impact analysis should lead to the preparation of an impartial report of the envisioned project. It should neither be a decision document nor it should make recommendations to planning decisions. It should just distinguish between facts and opinion and support the opinion with qualitative analysis. In fact it should not include subjective judgements, too.

Environmental impacts analysis could be best integrated with existing developmental control system (if any), by inviting reactions of various "interest groups".

Environmental impact analysis should be taken as the main basis of development control. In light of growing knowledge of our natural processes, there is a need for improvement in practice, whether this is a separate process or part of development control.

In URBANIZATION context the role of environmental analysis is very meaningful in terms of proper LAND RESOURCE management and in our case particularly to safeguard the depletion of prime agricultural land, water front and public open space which are fast disappearing with ruthless on-slaught of built-up area. This does not imply that urbanization process is something to be dreaded of. In fact a healthy trend with judicious and sensitive land use could bring whole lot of benefits to people and the Society. In terms of far reaching consequences the following sectors must go through with concept of environmental impact analysis, procedure right from project formulation stage.

1. Alignment and Road construction of significance.
2. Individual Building construction of far reaching consequence.
3. Power line alignment.
4. Large scale construction works or major or

engineering works.

5. Water resource management and allied construction works.
6. Drastic change of land use and morphology of town.
7. Change or interference with an environmental NICHE.

Complete thinking of 'Cause and effect' (not isolating one from another) should be given so that not to undermine land-scape 'vis-a-vis urban design and city-scape.

We have to recognise the fact that with increasing human activity we are utterly dependent on natural processes right from chemical nutrition that sustains our food productions to genetic information so that to enhance QUALITY OF LIFE

The ability of our ecosystem to persist and perform their functions in the face of environmental changes caused by human activities is related to complexity of ecosystem. Man as such for his very survival has to refrain from being destabilizing force for his short range interest. The triangle consisting of **PEOPLE, BUILT ENVIRON, NATURAL ENVIRON** constitutes a very VITAL study. In fact environment is indicator of WELL-BEING. This clearly indicates, Environmental quality. It has to be borne in mind that a variable landscape will support more species comfortably. Manipulation of Environment has to be sensitive to ward off deterioration. We have to realize that it is finite world with environmental resistance as its consequences. Our eco-system is very much based on "Donor's controlled model". Hence we have to be sensitive enough to the cumulative changes and above all the coevolution which shapes organization in eco-system.

First of all let us ask what makes a city and town which is product or urbanization living? I think by bringing people together they create a collective surplus of conviviality in the community, helps to bring buildings together spatially and they collectively give visual pleasure. Elements that go to create the environments such as buildings, trees, water, land—weave them together and a drama is released—for city is dramatic event in environment. Urban development deals with aesthetic which determine order & form of a city, takes care of fragility of urban space, and creates perception of city as a whole. The

unity of city as an absolute fact lies in unified experience. The essential aspect is that all parts of city so experienced must be recognizable as parts of the whole city. When in design we see consistency with urban forces at work harmony with social, political and economic facts and the design acquires a quality of naturalness of acceptance.

Cities should be alive and their **living quality** must come through the **articulation** of various parts of the city, in its adaptation and in its growth, without adverse effects on eco-system. We should be aware a city tells us things and our body responds to the perception.

The organic relations of the city, the interaction of its transportation and its land use, its morphology and landscape no **less than** of its people and their recreational areas are important themes of design. Understanding of city and our individual relationship to it means conviviality and a kind of coherence. City speaks to us more directly as a place where opportunity is extended or denied where life is valued or suppressed, where the common good is recognized or ignored. The city in short declares whether it is true or false to life thus in aesthetic term it provides "Ideated Satisfaction". We realize its entity and live its life.

In *Nepal*, scores of towns of different scales are coming up with galloping urbanization. We do have couple of town planning offices and a physical planning department at National level to give desired guided direction to our town and cities. But their work parameters are limited and more over their orientation is basically town planning or physical planning only and there is the least

consideration for impact assessment of the said actions in terms of built form. Apart from visual pollution of our skyline by ugly structures, the land resource too has been badly molested. Whether it is matter of individual architectural work as a piece of isolated action or continuous constructional complex (housing work or urban design complex) it is just matter of degree of interference on land as well as sky-line, and we must take into account of likely impacts. We have numerous examples of molestation of our centre of cultural heritage, religious complex of unmatched level and beautiful open spaces, to quote such as Durbar Square complexes and their urban fabrics, environmental condition of Pashupati Temple the once magnificent stretch of Tundikhel. It would not be difficult to trace the causes they are pretty obvious, as for the EFFECTS. We are seeing, smelling and testing them right now.

The moral is that let us wake up from our hibernation and give a little thought to environmental assessment of our urban development actions to mitigate the hidden negative impacts. Perhaps constitution of "Urban Development impact analysis cell" will be a good contribution to serve as a timely warning system, for urban development schemes of various scales. So let us open a new SCENARIO of development with new dimension of environmental assessment built into our project formulation stage of Urban Centre.

USER CENTERED DESIGN AND USABILITY IN MOBILE APPLICATION

Sangita Sharma* & Sarbin Sayami**

Abstract

Mobile device have become a vital and obligatory gadget in everyday life which is making course of actions more efficient and effective by ensuring access to information needed in a form appropriate to the situations. Applications are being built with newer advancements which will assist users in time-critical, goal-driven tasks and a great emphasis is placed on the features and performance. The driving success of mobile phones is associated with usability. Usability issues have become a prime aptitude that is necessary for mobile business to survive in the wireless economy. Usability inquiry methods can play a more significant role during the application development life cycle, diagnosing usability problems and providing metrics for making comparative decisions.

Keywords: Mobile applications, Usability, User centered design, Usability testing.

Introduction

Mobile products have become a key indicator of consumers' life styles and primary tools for everyday life because they are taken along with everywhere, from home to work and to leisure places, and they not only provide communication whenever needed but also become a primary means for life management [1]. The acceptance rate and use of a mobile phone over the world are growing rapidly. A great emphasis is placed on the features and performance in development of mobile phones and user friendliness, termed usability, and are increasingly in demand. For the reason that: users are able and keen to use a variety of features of mobile phones and the facilities provided by mobile operators, usability is proved to be beneficial and thus this decreases need of the customer support and increases user satisfaction [2]. There are various guidelines for usability testing of desktop applications. However, those established concepts, methodologies, and approaches commonly used in traditional human-computer interaction research are not always applicable to mobile applications. Developing mobile applications is currently a challenging task due to the specific

* Information and Communication Technology, Asian Institute of Technology, st104641@ait.ac.th

** Asst. Prof. and HoD, Department of Computer Science, nec, sarbins@nec.edu.np

demands and technical constraints of mobile development. Furthermore, at the moment very little is known about the suitability of the different development processes for mobile application development [3].

Usability engineering (also termed as User Centered Design / Human Centered Design) is the field which deals with designing the usable products. Usability of software applications developed for mobile devices and its testing is an emerging research area that faces a variety of challenges due to unique features of mobile devices, limited bandwidth, unreliability of wireless networks, as well as the changing context (environmental factors). A fundamental procedure is usability requirement and usability testing. Because developing mobile applications with an easy-to-use interface is vital for successful adoption and use of applications, it is essential to focus on how to conduct an appropriate usability test using mobile devices in a wireless environment [4, 5]. Primarily this needs qualitative as well as quantitative usability assessments.

Perspective of Usability and User Centered Design

Usability is the practice of designing products so that users can perform required use, operation, service, and supportive tasks with a minimum of stress and a maximum of efficiency. According to ISO/IEC 924-11, 1998, usability is defined as the quality of interaction in a particular context, which is measured by the effectiveness, efficiency and satisfaction with which specified users achieve specified goals in particular environments. The benefits of adding usability to a product development process [6] include increased productivity, increased sales and revenue, decreased training and support costs, reduced development time and costs, reduced maintenance costs, increased customer satisfaction. However, there are barriers to embracing usability

- Lack of knowledge about what usability means, what are available usability techniques and development methods
- Ambiguity whether existing usability guidelines and standards valid for mobile applications as well
- Product development with tight delivery schedules
- A feeling that 'We already know what users want' and that 'Our system is intuitive'

- Perception that usability is expensive and usability activities are too hard to conduct
- The optional nature of usability activities

In general, it is impossible to specify the usability of a system (i.e., its fitness for purpose) without first defining who are the intended users of the system, the tasks those users will perform with it, and the characteristics of the physical, organizational and social environment in which it will be used.

A key methodology for carrying out usability is called User Centered Design (UCD). It is a structured product development methodology that involves users throughout all stages of product development, in order to create a product that takes into account users' needs, limitations, and favorites. The principles of UCD [7] are early focus on users, their tasks and environment; the active involvement of users; practical measurement of product usage; an appropriate allocation of function between user and system; the incorporation of user-derived feedback into system design; iterative design whereby a prototype is designed, tested and modified repeatedly.

Iterative User Centered Design Process

User Centered Design, in the whole mobile application development cycle, is an iterative process where feedback from end users is brought into design in different stages of the development cycle. Designing the system usually involves - a problem definition phase, the development of a functional specification, a building phase, and a testing or evaluation phase.

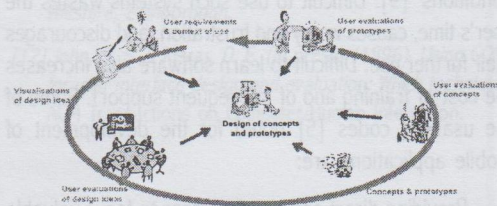


Figure 1 Iterative User Centered Design Process [8]

The steps in the iterative UCD process are crudely illustrated in Figure 1 (adopted from [8]), and involve an iterative cycle of specifying various steps. One essential prerequisite for UCD is to define in detail the context of use of the product where context is a description or understanding of the actual interaction events. This provides a structured

approach to gather and document information about the characteristics of the intended users, tasks and environments. The resulting specification of context of use can be used to update design, and to specify valid and consistent evaluations. User data is the basis for usability requirements where the target levels of usability of the product under development are determined. Verifying the target users who are going to use the system is the foremost step in UCD method. Analysis is made by stakeholders in order to determine the pool of most valued potential customers and their prioritized requirements and wants. Set of user profile elements helps in this matter. Task analysis methods are performed to make out users' actions or triggers, processes of completing assigned tasks, and ultimate goal of the users. Requirements are extracted from the task analysis that is in our hand and are documented in use cases. During the product design, the users' object model significant to the users should be incorporated. User experience is then analyzed concerning every flow of allocated tasks and information entailed in completing tasks. Followed by this is UI design which requires all the information from the earlier phases. Interactive design and usability evaluations typically form an iterative process. Prototypes are made at several levels. The prototype is verified equally against usability requirements. The process is iterated through several iterations advancing from low fidelity prototype to fully functional product.

Mobile Device Usability

Mobile device usability refers to 'the capability of mobile application to be understood, learned, used and be attractive to the user, when used under specified conditions' [9]. Difficult to use such systems wastes the user's time, causes worry and frustration, and discourages their further use. Difficult to learn software also increases the cost of training and of subsequent support. Some of the usability codes [5] noted for the development of mobile applications are:

1. Providing direct and simple access to focus valuable contents by summarizing information with very few keystrokes or text entry.
2. Reducing page navigation by using simple hierarchies like the existing phone menus which users are already comfortable with.
3. Decreasing downwards scrolling by shortening the

displayed text.

4. Simplifying the navigation and replacing text input with list selection.
5. Merging the theoretical and empirical evaluation to assist in further research.

Because achieving a high level of user satisfaction is critical to the success of mobile applications, usability testing is a mandatory process to ensure that a mobile application is practical, effective, and easy to use, especially from a user's perspective.

A number of significant challenges are observed while evaluating the usability of mobile applications due to unique features of mobile devices and wireless networks. Some of the issues are mobile context, connectivity, small screen size, different display resolution, limited processing capability and power, data entry methods, and multimodal interfaces [3]. These issues should also be carefully examined during designing and conducting usability studies for mobile applications.

Methods for Evaluation of Usability

Due to the size of small screens, non-traditional input methods, low resolutions of the displays, and a wide range of user environments, there are many challenges and constraints in mobile device interfaces. Many explorations are still to be made on usability testing methods in order to overcome these limitations. Because of smaller screen displays with lower graphical capabilities, early usability studies for mobile phones focused on the presentation of menu interfaces to perform basic functions and assist services such as making calls, receiving calls, diverting calls, setting up message folders, and changing ringing tones, rather than on how to present lengthy texts on restricted mobile screen [10]. As a consequence experimental studies to measure task completion time and error rate founded on various interface alternatives and menu hierarchies are being performed.

Usability can be evaluated qualitatively via laboratory experiments, surveys, questionnaires (e.g., QUIS, SUMI, CSUQ, MUSiC, etc.), interviews, etc. However, these tell us only the user's reaction as the user perceives the situation. Thus some kinds of questions, *for instance, to do with time measurement or frequency of event occurrence*, are not usually reliably answered [11]. However, usability can be quantitatively evaluated via theory-

based approach GOMS (Goals, Operators, Methods and Selection rules). GOMS, one of the most widely known methods, describes a task and user's knowledge of how to perform the task in terms of goals, operators, methods and selection rules. GOMS analysis can also predict how people will use a proposed system. In comparison to prototyping and user testing, GOMS produces a priori quantitative predictions of performance at an earlier stage in the development process. GOMS predicts execution time, learning time, errors, and also identifies those parts of an interface that lead to these predictions, thereby providing a focus for redesign effort [12].

Conclusion

With the rapid advances of mobile technology and applications, effective usability testing becomes increasingly important for the design, development, and deployment of successful mobile applications. There arises an interesting and even more challenging research question: how can usability of mobile applications be evaluated effectively? Traditional guidelines and methods used in usability testing of desktop applications may not be directly applicable to a mobile environment. Therefore, it is essential to develop and adopt appropriate research methodologies and guidelines that can evaluate the usability of mobile applications.

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WATER SUPPLY AND SANITATION IN A TERAJ VILLAGE: SITUATION ANALYSIS OF SONBARSHI VILLAGE IN KAPILVASTU DISTRICT IN WESTERN NEPAL

Sabitri Tripathi*

Introduction:

"Sanitation" embraces all conditions that can potentially affect health, especially with regards to water supplies, excrete and wastewater disposal, refuse disposal, vectors of diseases, housing conditions, food supplies and handling of food wastes, atmospheric conditions and the safety of the working environment. In Nepal, the aspects of sanitation focused in the policies and development program are: personal hygiene and community sanitation; food hygiene; handling, storage and use of drinking water; method of disposal of human excreta; solid- and liquid-waste disposal and disposal of animal wastes. In Nepal, 82 per cent of the population has access to clean drinking water and that coverage of sanitation, in terms of access to toilet, is just 39 per cent (Nepal Living Standard Survey Vol. 1, 2004). Nepal's Tenth Plan (2003-2007) aims to provide 85 per cent of the population access to water supply and 50 per cent with sanitation services. The target spelled out in the Rural Water Supply and Sanitation National Policy (2004) is to achieve universal coverage in water supply and sanitation by 2017. The government recently drafted National Water Plan (2002-2027) in an effort to meet the increasing demand for drinking water and sanitation facility. The plan identifies ways and means to achieving the ambition of universal coverage of water supply and sanitation by 2017. Furthermore, solid waste management has been explicitly placed at the forefront of the national planning agenda with the prime concerns on pollution control and sound environmental management.

This target set by the government in meeting the drinking water supply and sanitation target seems challenging considering the water supply and sanitation coverage to date. Even in the current coverage, serious differentials in rural and urban coverage can be noted. Further, rural areas in Terai have been lacking far behind the water supply and sanitation coverage. This would be critical to meeting the ambitious target for water supply and sanitation coverage set by the government in line of the Millennium Development Goal (MDGs).

This study was carried out as a part of ongoing research initiative at Nepal Engineering College (*nec*) on Development of Appropriate Safe Drinking Water

* Assistant Professor/Coordinator, SDW Project, DelPHE, Nepal Engineering College

Supply System for Slums and Squatters in Nepal supported under Development Partnership in Higher Education (DeIPHE) Program of DFID. This study was taken up in the course of selection of study sites for the mentioned study and looks into the status of water supply and sanitation in a Terai village. Considering low coverage of water supply and sanitation in rural Terai, this study attempts to unfold some of the facts pertaining to water supply and sanitation in the context of a typical Terai village, inhabited predominantly by the Madhesi Communities.

The study was carried out in Sonbarsi village, located in Gauri VDC in Kapilvastu District. This village was specifically selected for this study as this typically represents a Terai village in most aspects.

Origin of Sonbarsi Village and Caste Differentials of Inhabitants

Sonbarsi village is located in ward 9 of Gauri VDC, in the southern part of Kapilvastu district. Sonbarsi village came into existence some 80 years ago. All lands in this village was paddy field prior to the settlement, belonging to landlord of Bhagwanpur village who owned most lands in ward 8 and 9 of Gauri VDC. The landlord of Bhagwanpur had many tenants and laborers to work in the agricultural activities in the farm. These were essentially landless people belonging to lower caste groups. The agricultural activities in those days were limited to mono-cropping of monsoon paddy, where labor demands were limited to few months during transplanting and harvesting and threshing of paddy. Most lands used to remain fallow during winter and spring seasons, therefore the labor needs in farm activities in other seasons were lower. With time the landlord started facing labor scarcity, probably due to increase in the intensity of cropping. This necessitated search for additional labor to work in the landlord's farm. The landlord brought five families from outside the District to work as labors. These families were given a piece of land to build their houses and also some land in lieu of their labor for working in the landlord's farm. This led to the evolution of Sonbarsi village with five families who were early settlers in the village. With time the number of households in the village increased due to separation of families of earlier settlers and also migration of other families in the village.

The early settlers and those who came to settle in the

village in the later phases belonged to Lodh, Chai, Nai, Pasi and Dhobi castes. These castes in Terai are occupational caste groups who besides working as agricultural labor have specific roles in the society, as stated hereunder:

Lodh: People belonging to Lodh caste are generally engaged in agricultural works. They plough lands and keep livestock. Raising milk animals, generally buffaloes, in this caste are common.

Dhobi: People belonging to this caste groups are generally engaged in washing clothes. They are either paid in cash or in kind for their work.

Chai: This caste in western Terai is generally engaged in fishing. They catch fish from rivers and ponds for household consumption and also for sale at the local level.

Nai : These are barbers who are engaged in hair cutting. People of this caste have also very important roles during deaths and marriages and other social and religious rituals. For their labor the payment of wage is either in cash or in kind.

Pasi: They are untouchable caste and engaged in keeping pigs and cattles.

Teli: The household of this caste are known for their work in expelling oil. Earlier these households used to keep wooden oil expellers operated by bullocks for expelling oil from mustard, linseed and other oil seed crops. With the installation of mechanical oil expellers, this role of Teli households has greatly decreased.

Although the primary purpose of the landlord in bringing these households to settle in Sonbarsi village was to create additional labor force to work in the farm, the landlord also needed occupational castes who could be engaged in other important social, cultural and religious activities. The reason for bringing Nai and Dhobi was that people of these two castes have very important role in the social rituals and religious activities in the Madhesi communities. Besides their engagements in regular hair cutting, Nais have important roles in the rituals pertaining to marriages and deaths. For example, Nai women put red color in the feet of bride and groom for the first time during marriage ceremony. Similarly, Dhobi women put the red powder (sindur) at the forehead of the bride from her own forehead as symbol of blessings for longevity of her husband.

The number of households in Sonbari has now increased to 66 with the total population of 528. The increase in the number of households has been due to increase in the population and separation of the families of the early settlers. There were also new migrants who came to settle in the village in the later times. The occupational castes who were brought to the village continue to perform their social and religious roles, however their engagements in these roles has been decreasing over time.

The distribution of households by caste in Sonbarsi village obtained during the inventory study is presented in Table- 1. Of the 66 households in the village, Chai are in majority followed by Pasi and Lodh. The number of households belonging to Dhobi, Nai and Teli caste is 6, 6 and 1, respectively.

Table- 1 Distribution of Population by Caste in Sonbarsi Village

	No. of households	Percentage
Chai	25	37.80
Lodh	13	19.69
Pasi	15	22.70
Dhobi	6	9.09
Nai	6	9.09
Teli	1	1.50
Total	66	100.00

Source: Field Survey

Socio-Economic Status of the Households

All the households residing in Sonbarsi village are engaged in farming as their main occupation. These households are essentially from lower social and economic strata. Though all the households are Hindu by religion, those belonging to Pasi caste are considered untouchables and restrained from serving food and water to other castes.

The distribution of landholding size of the households is presented in Table- 2. This clearly illustrates that majority of the households are smallholder with their landholding size smaller than 1 bigha (1 bigha= 0.67 ha). Only 13 households have landholding size larger than 1 bigha,

however none of them have landholding size larger than 2 bigha. As many as 16 households in the village are landless who work as agricultural labors to earn their living. Some households have one or more members of the family seasonally migrating to India for wage earning, however the number of such households in the village is very few.

Table- 2 Distribution of Households with Landholding Size in Sonbarsi Village

Landholding Size	No. of Hhs	% of Total
> 1 bigha	10	16
< 1 bigha	40	60
Landless	16	24

Source: Field Survey

The average monthly income of the households is presented in Table- 3. Based on the information provided by the households on the sources of their on-farm and off-farm income, the average monthly income of majority of the households (29 out of 66) was noted to be less than Rs. 2,000.00 per month. Only 13 households were with average monthly income larger than Rs. 3,000.00 per month. Of the off-farm income sources, daily wage earning in the vicinity and seasonal migration to India for wage earning was important.

With the average monthly income of 81.7% of the households less than Rs. 3,000 per month, the average daily income would come out to be Rs. 100.00. With the average family size of 9 members in most households, the daily earning per person would be Rs. 9.9.

Table- 3 Average Monthly Income of the Households in Sonbarsi Village

Average Monthly Income (Rs.)	No. of Hhs	% of Total
> Rs. 3,000	12	18.3
Rs. 2,000-3,000	25	37.8
< Rs. 2,000	29	43.9
Total	66	100.0

Source: Field Survey

There is only one public primary school in Gauri VDC which is 2 km away from Sonbarshi village. Children need to walk at least 8 km to reach Taulihawa, the district headquarter, for high school level education. Majority of the people in Sonbarsi village are illiterate, however most

households have started sending their children to school. This has been a new trend that started only recently. The number of school going children is shown in Table- 4. Most of the school going children is 6-15 years of age. The dropout rate after primary and lower secondary level of education is very high. The number of school going girl children is far lower than the boys and also the drop out rates of the girls from the school is high. Further, daily attendance of school going children was noted to be poor. Only small numbers of students were attending the school regularly. Most were irregular in school because of engagements of children in the farm and other household works.

Table- 4 Number of School Going Children in Sonbarsi Village

School Going Children	<5yrs	6-15yrs	15yrs above
Girls	0	30	0
Boys	0	52	0

Source: Field Survey

Sources and Accessibility of Drinking Water

Hand pumps are the sole source of drinking water in Sonbarsi village. There are all together 14 hand pumps, of which 3 hand pumps are public and 11 are privately owned. The public hand pumps are installed with the support of VDC and development agencies. The privately owned hand pumps essentially cater to the needs of the owner households. As many as 55 households are dependent on the 3 public hand pumps, showing the dependence of over 18 households per public hand pump (Table-5)

The accessibility to drinking water source, based on distance traveled and time spent to fetch drinking water from the hand pump is shown in Table-5. This shows that even those households who depend on public hand pump for drinking water need, majority need to walk for less than 100 m to fetch water. The average time spent in each turn of drinking water fetching for majority of the households was noted to be less than 15 minutes and only 4 households reported that they need to wait in queue in fetching drinking water. This clearly states that accessibility of drinking water is not a critical to majority of the households as fetching of drinking water does not involve much drudgery. In most households however

women and children were found to be responsible for fetching the drinking water.

Table- 5 Sources and Accessibility of Drinking Water by the Households in Sonbarsi Village

Private hand pump(11)	Public hand pump(3)	Distance to fetch			Time to fetch (minutes)		
11	55	<100m	>100m	Self	<15	15-30	Queue
		27	16	11	47	18	4

Source: Field Survey

Sanitation Status of Households

In this study attempt was made to assess the sanitation status of the households in terms of knowledge and practice of personal hygiene, waste management and cleanliness for healthy living. Though it was not possible to obtain complete picture of sanitation status of households within the short duration of this study, some facts and observations, as stated hereunder, illustrate the state of sanitation at household and community levels in Sonbarsi village.

The sanitation status of households in terms of access to toilet, washing hands with soap after toilet use and drainage of waste water from homestead, is presented in Table- 6. None of the households in the village have toilet constructed in the homestead. People excrete in open field and use stream water or pond water for cleaning. Women, for privacy reason, defecate during evening or early morning. Young children are made to excrete in the open space within the homestead that creates objectionable sanitary condition. Though, in the course of this study, the frequency of occurrence of diseases and parasite infestation due to unsanitary excrete disposal was not looked into, the people in the village indicated of serious parasite infestation in young children.

Some NGOs working in the area have included toilet construction as important component of their development support. However, in the program of toilet construction supported by the NGOs, the households are required to contribute part of the construction cost to be able to obtain the support of NGOs. Considering the level of income of most households, they consider the cash contribution too heavy for toilet construction. Further, the people in rural Terai have long tradition of excrete in open space that has deeply embraced in their tradition and daily routine. They believe that while they go to

excrete in open they get opportunity to walk a distance in the morning and in the process they can also inspect their farm.

Washing hands with soap after toilet use was found to be practiced only in 19 out of 66 households (Table 6). Majority of the households were found to be using mud for washing hands after toilet use. The households seemed unaware of consequences of the unsanitary condition resulting from improper cleaning and washing.

The provision of some form of drainage for waste water disposal was noted to be developed only in 19 out of 66 households in this village. In others, practice of disposing waste water in open was observed. While this is not as serious problem during dry season, absence of drainage for disposal of household's waste water becomes extremely serious during monsoon that leads of water logging around the homestead that becomes breeding ground for mosquitoes and house flies.

In most households, the waste water in the homestead also includes the waste and urine coming from livestock shed built close to the house. This produces objectionable odor and worsens the sanitation around the homestead.

Table- 6 Sanitation Status of Households in Sonbarsi Village

Sanitation Attributes		No. of Hhs
No. of Hhs with Toilet:		
	With	0
	Without	100%
Washing Hand with Soap after Toilet Use:		
	Yes	19
	No	47
No. of Hhs with Drainage of Waste Water:		
	With	19
	Without	47
Types of Drainage System in the Hhs		
	Open	100%
	Closed/Piped	0

Source: Field survey

The study also looked into the methods of waste management practiced by the households in Sonbarsi Village (Table- 7). Haphazard disposal of household's waste was found to be practiced in majority of the households. Only 13 out of 66 households were found practicing composting of household waste along with the animal wastes (dung and litter) collected from livestock shed. Similarly, only 13 out of 66 households were disposing the waste at designated place while others had no fixed place for the waste disposal.

Improper disposal of household waste was noted to be serious sanitation problem in this village. People seemed unaware of health consequences resulting from improper waste disposal. Majority of the households were found unaware of importance and method of composting as means of waste management and also as source of valuable fertilizer. Since majority of waste generated in the households in the rural area are organic in nature that can be easily composted, they need to be educated on methods of compost making and its value as fertilizer.

Table- 7 Methods of Management of Household's Waste in Sonbarsi Village

Methods of Hh's Waste Management	No. of Hhs
Haphazard Disposal	40
Open Dumping at Designated Place	13
Burning	0
Composting	13
Any Other (Pls. specify):	-

Source: field survey

Findings and Conclusion

Safe water refers to a water supply which is of a quality which does not represent a significant health risk, is of sufficient quantity to meet all domestic needs, is available continuously, is available to all the population and is affordable. In Sonbarsi village quantity of drinking water supply is not the serious problem but coverage and quality of drinking water seems problematic. The status of sanitation in the village and in the homestead was noted to be extremely poor. This is largely due to poor level of awareness of the people. Although the study did not look into the frequency of ailments due to poor sanitation in and around the homestead, this is definitely the major cause of ailments and health related risks. In Sonbarsi