Nepal Civil-Military Emergency Preparedness
Seismic Vulnerability Procedures Workshop
Final Recommendation Report

July 2011
Cover Photo: CMEP Seismic Vulnerability Procedures Workshop participants conduct field assessments at Tribhuvan International Airport (top) and a local bridge (bottom) in Kathmandu, Nepal.
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1. INTRODUCTION

The U.S. Army Corps of Engineers’ (USACE) Civil-Military Emergency Preparedness (CMEP) program was requested by the U.S. Pacific Command (USPACOM) and the U.S. Agency for International Development (USAID) to conduct a Seismic Vulnerability Procedures Workshop in Kathmandu, Nepal. This event took place 18-28 April 2001, and was hosted at the Nepal Army Club. The workshop consisted of two parts:

1) An educational exchange on seismic retrofitting design, standards, and evaluation procedures; and

2) Visual seismic vulnerability assessments of four (4) bridges in the capital city of Kathmandu, as well as structural and non-structural elements residing at the Tribhuvan International Airport (TIA).

A team of U.S. Subject Matter Experts (SME) traveled to Kathmandu to assist Nepal’s Ministry of Defense (MoD), Ministry of Physical Planning and Works, and Civil Aviation Authority of Nepal (CAAN) in performing these tasks, as well as reviewing guidelines and procedures for conducting future seismic evaluations. The U.S. team consisted of SMEs from the Federal Highway Administration (FHWA), Federal Aviation Administration (FAA), U.S. Office of Defense Cooperation (Kathmandu), U.S. Agency for International Development (USAID), and USACE. The U.S. SMEs worked with the Nepal Army, the Department of Roads, CAAN, the National Society for Earthquake Technology (NSET), Kathmandu University, Tribhuvan University, and others to accomplish the assigned work defined in the original proposal. This holistic approach to seismic technology exchange and field evaluations strengthened Nepal’s technical capacity and furthered their ability to prepare for and respond to a catastrophic earthquake. However, much work is still to be done.

The first week of the workshop focused on seismic vulnerability assessment procedures. SMEs from USACE, FHWA, and FAA led separate bridge and airfield courses, which discussed guidelines, procedures, and methods for performing accurate and timely seismic assessments. National Highway Institute (NHI), American Association of State Highway Transportation Officials (AASHTO), International Civil Aviation Organization (ICAO), International Aviation Safety Assessments (IASA), and International Standards Organization (ISO) guidelines were featured. Additionally, focus was placed on designing and retrofitting adequate displacement and ductility capacity. Assessment criteria looked at the consequences of elastic design approach, including seismic deflections, the ratio of gravity load to seismic force, and inelastic structural actions and associated concepts of ductility and capacity design. Additionally,
soil considerations and historical earthquake events were examined by the USGS and NSET to determine liquefaction characteristics commonly experienced in the Kathmandu Valley. More geotechnical information is still needed at TIA, and hence this report recommends a specific soil investigation be conducted as soon as possible. Examples of successful U.S. and international seismic retrofitting designs were also showcased during the educational exchange.

The second week of the workshop featured seismic vulnerability assessments of four (4) bridges in the Kathmandu Valley and facilities at Tribhuvan International Airport. The U.S. SMEs evaluated how the Nepali engineers conduct their seismic vulnerability assessments, and provided suggestions for enhancement based upon U.S. national and international standards. Using the materials obtained and knowledge learned from the educational exchange, the bridges and airport facilities were rated jointly by all participants, and their final recommendations are found in this report. Maintenance issues were not discussed, as the evaluations were purely seismic. However, there are many maintenance issues present at both bridge and airfield facilities that still require immediate attention (ex. scouring at bridge locations or proper airfield pavement patching at TIA).

This report contains recommendations that were observed in the classroom and the field for specific facilities and infrastructure. It is by no means a comprehensive assessment of Kathmandu, and the recommendations are only valid for the facilities visited. For the four bridges that were evaluated, it is assumed that none of them will survive a catastrophic earthquake (> 8.4M). As a result, alternative terrestrial transportation means needs to be examined as soon as possible, and those options need to be put into place and exercised regularly. At TIA, the lack of as-built drawings hampered SMEs’ ability to conduct complete seismic assessments. As a result, the SMEs had to make several assumptions, which are described in this recommendation report. The bottom line is TIA needs a geotechnical soils investigation and pavement strength assessment performed as soon as possible to determine the amount of runway that will be available after a catastrophic earthquake. This will indicate liquefaction potential, slope stability, water table levels, and what type of aircraft can be used after a large-scale earthquake has taken place. Furthermore, there is no natural disaster emergency operation plan for TIA. Therefore, one needs to be generated as soon as possible and integrated into Nepal’s National Response Plan efforts. This report includes preliminary suggestions for inclusion in the emergency operation plan, as well as a DRAFT land-use planning map for TIA. However, all recommendations need feedback and input from TIA, CAAN, the Nepal Army, and others before they are useable and effective tools.
2. SEISMIC VULNERABILITY

The Himalayan range is the largest mountain system on earth, and includes the planet’s highest peaks. It is also one of the world’s most seismically active zones. Once a separate landmass, the Indian subcontinent began to collide with Eurasia about 50 million years ago. The same plate tectonics forces that drove the collision remain at work today, pushing India northward at a rate of about 2” per year. This generates stress along locked faults that must eventually be released in large earthquakes. Devastating earthquakes have struck along the Himalayan arc throughout recorded history, including several earthquakes with magnitudes around 8.0 around the start of the 20th century: the 1897 Shillong Plateau, 1905 Kangra, 1934 Bihar-Nepal, and 1950 Assam earthquakes (Figure 3). More recently, the 2005 magnitude 7.6 Kashmir, Pakistan earthquake claimed over 75,000 lives. Compared to past and expected future great Himalayan earthquakes, this earthquake was relatively modest in terms of magnitude and spatial extent of the damage zone.

Nepal sits squarely atop the active plate boundary zone, extending about 500 miles from east to west along the Himalaya arc and about 100-150 miles north to south. The entire country is thus considered a highly active earthquake zone. In recent years, scientists’ assessment of earthquake hazard along the Himalaya in general, and in Nepal specifically, has improved dramatically. The continuing northward motion of the Indian subcontinent has been measured precisely with GPS; these data, in combination with geological investigations, have been used to identify the most hazardous faults along the range. The main suture zone between the Indian subcontinent and the Eurasian landmass, known as the Main Frontal Thrust (MFT) fault, runs along the southern edge of Nepal.

Recent geological investigations have identified compelling evidence for a massive earthquake on the MFT in southern Nepal around 1100 AD. This earthquake is not documented in the historical record, which is extremely sparse around this time. The estimated magnitude of the earthquake, based on geological observations of the extent of fault break and the amount of motion on the fault, is 8.8. This earthquake was considerably larger than the more recent large Himalayan events mentioned above.

Figure 3 – (Left) Map of Himalaya region showing major earthquakes in 1897, 1904, 1934, and 1950. Small “beach balls” indicate locations of moderate earthquakes in the region; red arrows indicate the rate of motion of the Indian subcontinent as measured by GPS (Avouac et al, 2001). (Right). Map showing motion of Indian subcontinent towards Eurasia, with location of 2005 Kashmir earthquake (red circle).
Earthquakes this large are expected to strike infrequently, about every one thousand to few thousand years. The expected rate of great Himalayan mega quakes remains an open research question. Nonetheless, Nepal clearly faces substantial seismic hazard from a range of potential earthquake sources: mega quakes (close to magnitude 9) that recur on time scales of millennia; large (magnitude ~8) earthquakes like the 1934 event, recurring on a time scale of centuries; and relatively moderate (magnitude 6-7.5) earthquakes that will have a more spatially limited impact, but could have devastating consequences if they strike close to a population center.

The hazard associated with inevitable future Himalayan earthquakes gives rise to enormous risk. Through the 20th century, the population living in proximity to the Himalayan arc, including the population of Nepal, increased dramatically. Most of Nepal’s population lives in the Terai, a band comprising the lowest outer foothills of the Himalaya and the northern rim of the Gangetic Plain. The Gangetic, or Indo-Gangetic plain, extends over most of northern India as well as southern Nepal. This region receives irrigation from the Himalaya to the north; over time it has been built up by layers of flood plain sediments, creating fertile soils for agriculture. The total population now living in the Gangetic plain is now nearly 1 billion, approximately 1/7 of the world’s population. The population of Nepal was just under 30 million in 2010.

With high population density, proximity to the MFT, and layers of sediments that will serve to amplify earthquake shaking, earthquake risk is a major concern for the Terai. The region is also characterized by high liquefaction susceptibility; extensive liquefaction was documented in the Terai during the 1934 Bihar-Nepal earthquake.

Earthquake risk is also a great concern for the city of Kathmandu. The population of Nepal’s capital city is now just under one million. The city has grown dramatically in recent years, its growth fueled not only by natural population expansion but also by an influx of Nepalese seeking refuge from outlying regions plagued by political instabilities. Population density is now nearly 20,000 people per square kilometer,
or about 50,000 people per square mile; among the highest population densities in the world. Kathmandu is situated within a small valley surrounded on all sides by steep mountains. The rapidly expanding population has therefore driven rapid densification of the central city and an increasing pressure to build upwards, with a resulting hodgepodge of structures. Some of the more substantial new buildings are being constructed with reinforcement that will provide some measure of earthquake resilience (Figure 4); however it remains unclear whether building codes and code enforcement are adequate for the level of hazard. Typical construction throughout the city reveals prevalent poor design and construction practices. Ironically, the earthquake resilience of Kathmandu’s building stock has worsened in recent decades: the vulnerability of typical modern construction in Kathmandu is generally worse than that of traditional construction, which typically incorporated wooden structural elements and infill design that provide a measure of earthquake resilience. Early construction practices may have in fact evolved towards more resilient design, practices that have fallen by the wayside in the rush to build dwellings to accommodate the rapidly growing population.

Earthquake risk in Kathmandu is of particular concern because the city is a vital nerve center of the country’s economy. The 2010 Haiti earthquake, of relatively modest magnitude 7.0, illustrated the dramatic and tragic consequences of an earthquake disaster in a capital city in a developing country. The consequences for Nepal of a comparable or bigger disaster in Kathmandu would likely be much worse because Port-au-Prince is a port city, whereas the Kathmandu Valley is landlocked within rugged mountainous terrain.

Figure 5 - (Left pair of photos) Darbar Square in Bhaktapur before and after the 1934 Bihar-Nepal earthquake; (Right) Older, traditional building in Kathmandu.

The 1934 Bihar-Nepal earthquake provides a template for a future earthquake disaster in Kathmandu. This earthquake caused extensive damage, killing over 8,500 people and damaging over 80,000 buildings in Nepal (Figure 5). The city of Kathmandu sustained substantial damage. A repeat of a similar earthquake would have far worse consequences, not only because of the much higher population and population density, but also because of the greater vulnerability of the modern city. The results of recent scientific investigations also tell us that a future earthquake could generate even more severe and/or more prolonged shaking in the Kathmandu Valley: either a great Himalaya mega quake, with a magnitude comparable to that of the 2010 Tohoku, Japan earthquake, or a relatively modest earthquake, with magnitude around 7.0, that strikes very close to the city. Any large earthquake in proximity to Kathmandu will be followed by an aftershock sequence that will pose a prolonged hazard over a period of months if not years, and complicate relief/recovery efforts.
3. AIRFIELD STRUCTURE RECOMMENDATIONS

3.1 Summary

Visual field inspections of aviation assets at TIA were conducted by workshop participants to determine seismic vulnerabilities, as well as to ensure that the performance of the infrastructure can meet the prescribed Level IX Modified Mercalli Intensity Scale (MMI) earthquake code. The following critical facilities at TIA were inspected:

- Runway System
  - Runway system pavement (runway and taxiway)
  - Drainage system
  - Aprons
  - Side slopes and embankments
- Airport Surveillance Radar Facilities
  - Engine generator building
  - Generator fuel supply
- Crash, Fire, & Rescue (CFR) Facilities
  - Fire truck hangar
  - Foam Storage building
  - Foam mixing tank
- Air Traffic Control Tower (ATCT)
- Old and New VOR/DME Facilities
- Air Cargo Building Facilities
  - Cargo building (warehouse)
  - Firefighting water storage tank
  - Adjacent slope embankment above the Cargo building
  - Access road from the airfield to the cargo building
  - Electrical feed to the firefighting pump house
- Aircraft Fuel Farm
  - Fuel tanks
  - Firefighting water storage tanks
  - Fuel wall enclosures
- International Terminal Building
- Domestic Terminal Building
- Radar Approach Control Operational Building
- Emergency Generator Building

The mission of the field inspections was educational, and it helped the Civil Aviation Authority of Nepal (CAAN), the Nepal Army, TIA staff, the National Society for Earthquake Technology (NSET), and other organizations to develop a methodology to conduct future seismic assessments on a routine basis. As
such, the group completed the task of identifying deficiencies and assessing the level of involvement needed to develop an implementation plan that could effectively reduce the vulnerabilities in the future. The main recommendation is for the development of a TIA Emergency Response Plan, which will take into account the known deficiencies and allow CAAN, TIA, the Nepal Army, and others to be better prepared to respond after a catastrophic earthquake occurs.

As a part of the field inspections, a simple rating system was developed. The rating system emphasized the impact to operability if a facility were lost. Seismic vulnerability was classified as “L” (Low), “M” (Medium), and “H” (High). The classification was determined through the visual inspection of the facility. Retrofitting priority was classified as “1st”, “2nd”, and “3rd”. Priority rankings were based on the importance of the facility to the operational capacity of TIA. The ranking of 25 different TIA aviation assets can be found in the table below (Table 1). The list is not comprehensive, and only includes facilities that were visited during the workshop.

Table 1 - TIA Airfield Retrofitting Priorities

<table>
<thead>
<tr>
<th>Description</th>
<th>Vulnerability</th>
<th>Priority</th>
<th>Required Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIA Emergency Response Plan</td>
<td>L</td>
<td>M</td>
<td>H</td>
</tr>
<tr>
<td>Runway System</td>
<td>L</td>
<td>M</td>
<td>H</td>
</tr>
<tr>
<td>Fuel Pipe Connections</td>
<td>L</td>
<td>M</td>
<td>H</td>
</tr>
<tr>
<td>CFR Foam Storage Building</td>
<td>L</td>
<td>M</td>
<td>H</td>
</tr>
<tr>
<td>CFR Foam Mixing Tank</td>
<td>L</td>
<td>M</td>
<td>H</td>
</tr>
<tr>
<td>ATCT Cab/Shaft Junction</td>
<td>L</td>
<td>M</td>
<td>H</td>
</tr>
<tr>
<td>Domestic Terminal Building</td>
<td>L</td>
<td>M</td>
<td>H</td>
</tr>
<tr>
<td>Utility Lifeline Support</td>
<td>L</td>
<td>M</td>
<td>H</td>
</tr>
<tr>
<td>Runway System Pavement</td>
<td>L</td>
<td>M</td>
<td>H</td>
</tr>
<tr>
<td>Non-Structural Element</td>
<td>L</td>
<td>M</td>
<td>H</td>
</tr>
<tr>
<td>Description</td>
<td>Vulnerability</td>
<td>Priority</td>
<td>Required Action</td>
</tr>
<tr>
<td>---------------------------</td>
<td>---------------</td>
<td>----------</td>
<td>------------------------------------------------------------</td>
</tr>
<tr>
<td>Air Cargo Water Tank</td>
<td>✓</td>
<td>✓</td>
<td>Structural assessment, lateral bracing system</td>
</tr>
<tr>
<td>Fuel Farm Water Tanks</td>
<td>✓</td>
<td>✓</td>
<td>Structural assessment, lateral bracing, positioning</td>
</tr>
<tr>
<td>Runway System Drainage System</td>
<td>✓</td>
<td>✓</td>
<td>Regular maintenance (remove plants &amp; soil)</td>
</tr>
<tr>
<td>Fuel Tank at Radar</td>
<td>✓</td>
<td>✓</td>
<td>Structural assessment</td>
</tr>
<tr>
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<td>✓</td>
<td>Assessment of structural &amp; operation system</td>
</tr>
<tr>
<td>Radar Equipment</td>
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</tr>
<tr>
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<td>✓</td>
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</tr>
<tr>
<td>CFR Main Building</td>
<td>✓</td>
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<td>Air Cargo Building</td>
<td>✓</td>
<td>✓</td>
<td>Structural assessment</td>
</tr>
<tr>
<td>Fuel Farm Fuel Tanks</td>
<td>✓</td>
<td>✓</td>
<td>Structural assessment</td>
</tr>
<tr>
<td>International Terminal</td>
<td>✓</td>
<td>✓</td>
<td>Structural &amp; non Structural assessment</td>
</tr>
<tr>
<td>Radar Approach</td>
<td>✓</td>
<td>✓</td>
<td>Structural assessment</td>
</tr>
<tr>
<td>Emergency Generator</td>
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<td>✓</td>
<td>Structural assessment</td>
</tr>
<tr>
<td>ATCT Shaft</td>
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<td>✓</td>
<td>Structure assessment</td>
</tr>
<tr>
<td>VOR/DME</td>
<td>✓</td>
<td>✓</td>
<td>Structural assessment</td>
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Due to a general lack of “as-built drawings” available through the Civil Aviation Authority of Nepal (CAAN) and TIA offices, further structural studies are required to determine their capacity to resist earthquakes. These structural analyses, as referred to throughout this report, should include (but are not limited to) field determinations of structural component size and material; computer model development (two dimensional and/or three dimensional [depending of the importance of the structure]); and, completion of a structural analysis (using commercially available software) to determine prescribed earthquake stress and strain. Significant time and effort will be required to complete the structural analyses recommended in this document. Furthermore, an identification of all critical structural elements will be necessary. In order to identify some structural elements, removing of plaster material, wall coverings, and façades may be necessary. More specific requirements and recommendations can be found in Section 2 of this document.

### 3.2 Specific Recommendations

As is mentioned in Section 3.1 of this document, specific critical facilities at TIA were evaluated by U.S. and Nepal Engineering Subject Matter Experts (SMEs) for seismic vulnerability. The below recommendations were derived from observations made in the field, and these observations were cursory given the limited amount of time and access available. Further structural analysis is recommended on all observed facilities.
3.2.1 Runway System

The most important element of an aerodrome is the runway system. It allows aircraft to land and take off, and its usability and functioning capacity is directly related to the length and pavement status. The longer the runway is, then the larger the aircraft that can access it. The more maintained and durable the pavement system is, then the more the runway can be used and the more accessible it becomes to a variety of aircraft types.

TIA has one runway and one taxiway system (Figure 6), and they are both built above the natural terrain in an embankment. According to CAAN statistics, in 2010 the runway system experienced 99,292 aircraft departures and arrivals (19,417 international and 79,875 domestic). This is a moderate usage number compared to other countries, and is fairly significant for facilities that only have one runway available. To ensure the runway remains well maintained, maintenance procedures need to be performed regularly and supporting infrastructure systems need to be in place.

One of the major concerns identified during the runway system assessment was the water table level under the runway, taxiways, and airfield facilities. It is currently unknown, but is believed to me at a level that could potentially increase liquefaction, especially during the wet season. Increased water tables make soils looser, which in turns makes the ground more susceptible to shaking and motion during an earthquake. In addition to the runway system, an increased water table level makes the slopes at the edge of TIA’s runway and aprons prone to liquefaction. High water table levels or excessive surface water could cause a landslide, which will comprise the runway or access roads leading to critical airfield facilities such as the Cargo Building or the Fuel Farm.

For these reasons, a geotechnical soils investigation of the runway and surrounding region is the first priority in understanding seismic retrofitting requirements. A geotechnical soils investigation will provide factual information on water table levels, soil types, slope stability, morphologic granulometry of fill material, and the potential for liquefaction. This information can then be analyzed by engineers and seismic experts to determine how much runway will be available during a variety of earthquake events, and where likely problems may occur. Currently, CAAN staff has defined a minimum of 6,000 feet as the minimum length necessary for safe arrivals and departures. This requirement was determined using C-130 aircraft parameters and requirements. A C-130 aircraft is the most commonly used to transport relief supplies during an emergency.
The U.S. Army Corps of Engineers’ (USACE) Alaska District has issued a contractual scope of work to conduct a geotechnical soil investigation at TIA (Figure 6). The work will determine some of the seismic vulnerability that exists, and can help determine what requirements will be necessary to properly plan and prepare for a catastrophic earthquake. The geotechnical work is currently scheduled to be completed in October 2011.

In addition to performing a geotechnical soil investigation at TIA, it is also recommended that a Runway System Pavement Strength (RSPS)-Pavement Condition Survey (PCS) study be performed. This study will provide critical information, including the existing pavement structure of the runway system. Through an evaluation and quantification of pavement defects, the study will provide a rating number that is directly tied to the airfield’s ability to receive certain type of aircrafts (wide body, narrow body, etc.). Additionally, the rating number will determine the number of operations left in the pavement before major repairs are required. Establishing the status of the runway system pavement will assist CAAN and TIA with periodic maintenance requirements, management of the runway system, and a capability minimum to operate during emergency operations. This information is currently unknown due to missing as-built drawings and reports.

Following the completion of a PRSPS-PCS, it is also recommended that a Runway System Specific Response Plan be developed. The plan will address runway and taxiway failures in case of an earthquake, as well as the recommended materials and equipment necessary to perform repairs. The plan will tie directly with the TIA Airfield Emergency Operations Plan that is currently under development. The Runway System Specific Response Plan should consider, as a minimum, steps for storing corrugated piping and/or culverts, establishing areas within the airport campus to stockpile structural fill material, sand, cold-mix asphalt, steel plates, and other material that will allow for a rapid
patch or bridging of a large crack (more than 12” wide) either in the runway or the taxiways. With the same criteria, the Runway System Specific Response Plan will also include the recommendation to have immediate access to a medium size back hoe, a front end loader, a roller, and other earth moving equipment which allows for the rapid repair and patching of large cracks in the runway and taxiways.

Lastly, the workshop SMEs evaluated TIA’s runway drainage system. According to CAAN, the drainage system was installed to ensure water leaves the elevated airfield in an expeditious manner and does not cause erosion and degradation. During the seismic inspections, the ditches and water-conducting structures were reviewed. It was determined that the drainage system for TIA is adequate. However, the drainage system requires continued periodic maintenance to assure the drainage capability is maintained, and water is released in a timely fashion from the elevated plateau to the ground below.

### 3.2.2 Structural Assessment of Crash Fire Rescue (CFR) Facility

The Crash Fire Rescue (CFR) facility is comprised of three (3) main facilities; a modern multi-bay firefighting hangar (Figure 7), an elevated building used for storage of the chemicals and supplies required for foam formulations (Figure 8); and, an elevated tank used for the mixing of the foam and subsequent loading into fire engines (Figure 9).

The main observations of the vulnerabilities of these three facilities are as follows:

The multi bay hangar roof structure is connected to sturdy columns by a steel plate. Unfortunately, due to the lack of “as-built drawings”, the shear capacity of this connection is unknown and requires further structural analysis. The analysis will be necessary to determine the ability of the connections to withstand the lateral loads of the roof during an earthquake. The roof is built as a wing with a very sturdy structural system. During an earthquake, large lateral forces will be
inducted into the wing structure, and as a result, it will need to be restrained by the connections to the columns.

The foam storage building has a “soft” understory, defined by tall slender columns (without lateral bracing) between a sturdy base and large mass above. This facility requires further structural analysis (as defined in the introduction). The analysis will determine if lateral bracing will be required to ensure the structure does not buckle and collapse during a Level IX MMI earthquake. Due to the lack of cross bracing and the slenderness of the columns, it is expected that the foam storage building will fail during a Level IX MMI earthquake. As a result, the building will need to undergo seismic retrofitting measures, which include as a minimum, lateral bracing and the reduction of column slenderness by adding jacketing or a similar retrofitting technique.

For the elevated water tank, it is recommended once again that a detailed structural analysis be performed to determine the impacts of a Level IX MMI earthquake on the facility. Like the Foam Storage Building, it is anticipated that the water tank will require seismic retrofitting. Some of the recommended measures include increasing the capacity of the frame, adding a cross-bracing system to reduce the lateral load, and adding steel to the supporting structural members. The final structural analysis will provide the best and most prudent means forward.

3.2.3 Structural and Non Structural Assessment of the ATCT of TIA

The Air Traffic Control Tower (ATCT) is built with concrete panels forming a very robust tubular structure (Figure 10). Concrete tubular structures are very efficient in resisting the forces resulting from an earthquake. However, special attention should be given to the transition area between the cab and the shaft of the ATCT to determine the differences in stiffness between the sturdy shaft and the light cab frame. A detailed structural analysis will evaluate the capacity of the transition structure to withstand the forces of a catastrophic earthquake. In turn, a final determination can then be made, which will define the necessary retrofitting measures. Through visual inspection, it is not anticipated that the ATCT transition area will require retrofitting. However, a final recommendation is dependent upon additional information from the detailed structural analysis.

Recent earthquakes, like the 2002 Nisqually Earthquake in Seattle, have proven that the first elements to fail in an ATCT are the glassed panels. It is recommended to replace the existing glass at the cab level, with laminated glass. Two panes of low ferrous glass should
be joined through heat lamination with a material that has the same translucent index. This will ensure that if the glass were to fall, it would not fall in sharp pieces and injure people and damage equipment below.

The glass in the shaft should also be modified (Figure 11). It is recommended that a film lamination be affixed to the existing glass so that it does not break and fall into pieces. The lamination can be applied "cold" because the existing interior glass is not heat-treated. This will ensure the shaft stairway can be used as a safe evacuation path during an earthquake event.

The ATCT non-structural elements, such as cabinets, book shelves, ceiling tiles, Heat Ventilation/Air Conditioning (HVAC) equipment, and office furniture and equipment (copiers, printers, etc), should be restrained and reinforced to minimize their impedance to evacuation routes. Currently, they are not restrained and will most likely topple over during an earthquake event.

3.2.4 Aviation Fuel Farm Facilities

Although these facilities are under concession to NEPALOIL, it is still the responsibility of TIA and CAAN management to assure the availability of fuel for any emergency operation. Therefore, the concessionaire should be requested to perform the seismic hardening required to assure that fuel supplies will be accessible and operable after an earthquake event.

The NEPALOIL Fuel Farm and Distribution Tank facility requires further structural analysis. The structural analysis will determine the likelihood of failure at the facilities. Additionally, it will provide recommendations to determine the level of retrofitting required for hardening the structures to withstand the earthquake induced forces. This analysis will also define the type of flexible pipe connections needed to efficiently reduce the fuel distribution system vulnerability to seismic forces. The analysis will also define the necessary emergency response staff required to carry out structural repairs (ex. welder), as well as the type of equipment (ex. spill prevention kit) to complete the tasks.

Among the most important elements requiring attention at the Fuel Farm are: the spill containment walls (The walls will be analyzed to determine their ability to support the hydrostatic load of fuel.) ; the fire suppression water tanks (There is a discontinuity between the frame, which will cause severe
As a part of the emergency response plan for this facility, the fuel concessionaire manager (NEPALOIL) should appoint a permanent trained and certified welding staff (minimum one certified welder) to respond to pipe breaks and fuel spills. Additionally, the Fuel Farm should be fitted with welding equipment compatible with the Fuel Farm’s operation.

3.2.5 Domestic Terminal Facility

The Domestic Terminal is constructed with tall slender columns and no lateral bracing system (Figure 13). As a result, the facility is very vulnerable to earthquake forces. Coupling these forces with frequent usage (800-1,000 people during peak business hours), the number of casualties resulting from a collapsed structure could be terrible.

TIA and CAAN management has mentioned that the facility will be replaced in the next five (5) years. For this reason, the facility has been rated with a lower priority than normal. However, it is still recommended and critical that some form of cross-bracing system be installed as soon as possible to palliate the situation until the new domestic terminal is completed. A structural analysis should be performed to determine the type of cross-bracing system necessary to raise the domestic terminal from a rating level of “Imminent Collapse” (IC) to “Life Safety” (FS).

3.2.6 Other Facilities

A. Cargo Terminal Fire Suppression System

The cargo terminal fire suppression system depends on a 243 cubic foot storage tank (Figure 14). The tank does not have lateral restraints. Therefore, it is recommended that a simple lateral resisting structure, such as adding a 45 degree bracing system from the bottom of the steel structure to the concrete base, be added. The bracing system will improve the tank’s capacity to withstand lateral forces. (The tank may also require additional reinforcement of the side walls. A detailed structural analysis can determine if this is
necessary or not.)

B. Navigational Aids

The navigational aids (NAVAIDS,) like the VOR/DME (Figure 15), also require structural analysis to determine their capacity to withstand the forces created by an earthquake. This analysis should include all NAVAIDS, communication, operational support facilities (ex. Instrument Landing System [ILS]), and their ancillary guiding light array, remote transmitting and receiving facilities, and any other facility that ensures the maximum operational capacity of the airport.

Both the old and new VOR/DME facilities were visited during the assessment. The main deficiency observed was the counterpoise structure. The counterpoise is the circular metal structure surrounding the equipment shelter. It has very slender structural members, which may buckle if subjected to large lateral loads. Since “as-built” drawings were not provided for the VOR/DME, it is recommended again that a structural analysis be performed before any seismic retrofitting take place at the facility.

C. International Terminal

The International Terminal (Figure 16) is a modern facility built to Korean seismic engineering standards. Through visual inspections, it is believed to be designed for seismic loads. However, the lack of as-built drawings and specifications for this facility requires that a structural analysis be performed to verify these assumptions.

D. Miscellaneous Facilities

The adjacent buildings housing the Terminal Approach Control Operations, Emergency Generator, Airport Surveillance Radar, and the Cargo Terminal facilities are in the same condition as the International Terminal building. From preliminary observations, and based on historical information provided by TIA management, the facilities are most likely designed and built to some seismic code. However, again, the lack of as-built drawings and specifications force further structural analysis to verify their capacity and performance during a seismic event.
4. AIRFIELD OPERATION RECOMMENDATIONS

4.1 Summary

Tribhuvan International Airport (TIA) is expected to be the sole means of transportation for relief operations after a catastrophic earthquake. Although TIA meets, or exceeds, all appropriate International Civilian Airport Organization (ICAO) standards for normal aviation operations and contingencies, it was not designed to meet the needs of such a catastrophic seismic event. As a result, TIA will need outside assistance to handle the demands of a large-scale earthquake response and recovery mission. As such, changes in airfield operation preparedness will be necessary to ensure maximum capacity, capability, and response is achieved. An all-hazards emergency response plan will need to be developed for TIA and the entire aviation infrastructure within Nepal. This plan will need to be tied to the Nepal National Response Plan. Currently, neither an aviation-specific response plan nor a national response plan is in place.

In disaster response, there is no pre-scripted schedule unless it is developed in advance. Aircraft arrivals, for instance, can become overwhelmed with critical supplies, and relief workers delayed or denied access due to lower priority traffic. Since aviation is the fastest method to transport relief supplies and personnel, an aviation-specific Emergency Operations Plan is valuable and necessary to address the specific tools, methods, and procedures to recover and maximize aviation operations. The plan should integrate the total airport operations, including the movement and storage of anything on the airport property while protecting the complex airport safety factors. The plan must take total cargo and passenger flow throughput into account from touchdown of an aircraft to delivery at the point of need. Failure to do this induces a risk of affecting aircraft movement within the Airport Operating Area (AOA) and limiting airport capacity. Key risk factors identified in the structural portion of this report, such as the runway, taxiways, ramps, and Crash Fire Rescue (CFR) facility, are being investigated for seismic vulnerability and retrofitting needs to potentially reduce the impacts of an earthquake.

There are many factors that support a successful Emergency Operations Plan. Two of them include aviation safety and airport capacity. Aviation safety is the assurance that all airfield operations are conducted in a manner that allows the secure and dependable passage of aircraft, passengers, cargo, and employees throughout the AOA. This includes the approach and departure routes and pavement (runway, taxiways, and ramps) are free of debris and in good condition. Airport capacity is the ability to move aircraft on and off the airport. Weather and the ability to guide aircraft to and from the airport are major factors in the numbers of take-offs and landings possible. However, the availability of taxiways and ramps has more influence because they allow the runway to be cleared for the next operation. The inability to offload and move cargo in a swift and efficient manner severely restricted the airport capacity in the Haiti Earthquake (2010) response operations. The likelihood of a similar situation occurring in Nepal is high if an Emergency Operations Plan is not developed.

A final factor in defining airport capacity is the CFR services. Civilian aircraft require appropriate CFR capability before they can operate. Civilian aircraft increase the potential capacity of relief supplies that
can be transported per flight and are used to replace military aircraft.

The current limitations in natural disaster response at TIA are summed by the lack of a detailed emergency response plan specifically focused on airport emergency operations as well as an intrinsic assumption that current operational capacity is adequate, and that all airport personnel will be available for duty immediately. Although these are good “normal” airport emergency planning measures, which focus inside the airport’s property, they are dangerous assumptions since they rely on little to no impact to the physical components of the airport and/or the surrounding community. This is why, although very valuable, standard airport emergency planning does not fully address major natural disasters. A specific Aviation Emergency Operations Plan is warranted and necessary, and it should be developed as soon as possible.

The first airfield operation priority is follow-on design efforts, which focus on the factors discussed above and define the requirements for an airport emergency operations plan. All aspects of disaster response operations must be captured, placed in a proper time relationship, and planned from arrival, to delivery, to the point of need. This operation must also account for recurring issues such as aircraft refueling, servicing, etc. The final integrated plan will allow any scenario to be discussed with pre-scripted solutions described. An example would be how to stage a 200 bed mobile hospital. In order to answer this question in the context of airfield emergency operations, TIA, CAAN, and the Nepal Army will need to know how many C-130 missions are required, where is the first one physically located, where is the next one located, and finally, what materials are needed first and in what order? The minimal amount of time dealing with these types of issues will boost efficiency, reduce frustration, and promote rapid and effective decision-making.

The second priority is to take reasonable actions that decrease the amount of damage incurred at the airport. There are many reasonable actions available, including improvements to the CFR facility, runways (sub base, surfacing), fuel depot, cargo equipment, and others. Those recommendations have been clearly outlined in the structural assessment portion of this report (Section 3).

The third priority is to train as many responders as possible before an event occurs, and have a method to quickly integrate additional responders when necessary. There is no doubt that highly skilled personnel will be available to support the disaster response in Nepal. The Government of Nepal should be prepared to quickly apply their skills and talents where they can provide the highest value.

The fourth priority is to assess adjacent airfields (Table 2) or open spaces near TIA for possible support. This includes a full seismic and airfield operation assessment of aviation assets throughout Nepal, as well as neighboring regional facilities, such as Calcutta, to ensure foreign humanitarian aid can reach Nepal in a timely manner. The determination of open spaces for aviation use can be analyzed in a Geographic Information System (GIS), and the results can be added to the overall airfield land-use plan that is mentioned in detail in Section 4.2.3.
Table 2 – Nearest Airfields Adjacent to Tribhuvan International Airport

<table>
<thead>
<tr>
<th>Airport</th>
<th>KTM (miles)</th>
<th>Length (ft)</th>
<th>Elevation (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bharatpur</td>
<td>BHR</td>
<td>60</td>
<td>3799</td>
</tr>
<tr>
<td>Pokhara</td>
<td>PKR</td>
<td>90</td>
<td>4,701</td>
</tr>
<tr>
<td>Meghauli</td>
<td>MEY</td>
<td>70</td>
<td>3,560</td>
</tr>
<tr>
<td>Lukia</td>
<td>LUA</td>
<td>84</td>
<td>1500</td>
</tr>
<tr>
<td>Phaplu</td>
<td>PPL</td>
<td>77</td>
<td>2201</td>
</tr>
</tbody>
</table>

4.2 Specific Recommendations

4.2.1 Airfield Emergency Operations Plan

Currently there are multiple studies, reports, and other documents addressing aviation requirements and capabilities pre- and post-disaster. Additionally, there are multiple expectations, based on various levels of understanding of aviation throughout both civilian and military organizations without a common method to relate these expectations to critical assets. By choosing an existing standard, a master plan should be developed to create a Nepal Aviation Emergency Operations Plan. The National Fire Protection Association (NFPA) Standard 1600 (Standard on Disaster/Emergency Management and Business Continuity Programs 2010 Edition) is one of many excellent standards that could be used to develop the airfield emergency operations and recovery plan.

This plan should be developed as soon as possible. Furthermore, it should be developed in partnership between TIA, the Civil Aviation Authority of Nepal (CAAN), the Nepal Army, and international organizations and countries that would most likely deliver aid after a catastrophic event. The final plan should be incorporated into Nepal’s National Response Plan, which is currently under development under the leadership of the Ministry of Home Affairs (MoHA).

4.2.2 Airport Safety

There must be an adequate length of runway to support aircraft operations that is secure from animals, personnel, etc. The types of aircraft that can use the runway are dependent upon its length, which affects the overall airport capacity. There are currently actions underway to increase the probability that an adequate amount of runway (6,200 feet) will survive to support the design aircraft of the Boeing C-130.

Until weather becomes an issue, the airport will operate under standard Visual Flight Rules, which allows for maximum flexibility and flight operations. When weather becomes a factor due to low ceilings (cloud heights starting around 500 ft above ground level), then the airport operates under Instrument Flight Rules and ground-based instrumentation and airport traffic control is required. These ground-based systems are susceptible to damage from an earthquake and will require checks and verification prior to being used. This will take time, but there is little to moderate chance of weather...
impeding the actual operations as calculated. Therefore, from an operations perspective, there is minor value to pre-event seismic retrofitting efforts on any ground-based system other than the Airport Surveillance Radar (ASR). Recommendations for the ASR are included in the structural portion of this report (Section 3).

4.2.3 Airport Capacity

Airport capacity drives incident command. However, it is complex, with multiple factors that interrelate and influence each other and the total capacity. The first factor is the ability to move aircraft from the runway to an offloading and servicing location, and then return to the runway for takeoff. Current efforts are in place to evaluate and strengthen the AOA, which includes the runway, turn-off, taxiways and ramps. We will assume adequate runway, turn-off, taxiways, and ramps are available to support Boeing C-130 operations for this report. This assumption, of course, must be verified prior to dispatching aircraft for relief operations.

TIA does not have enough ramp space to support the calculated requirements. Ramp space utilization should be pre-planned and designed with additional parking, cargo management, and aircraft servicing (fuel, engine starters, tugs to push back, etc). Furthermore, ground control (movement of any and all vehicles within the AOA) should be designed and documented, and local airport personnel and relief workers should be trained.

There appears to be adequate space to provide aircraft parking and servicing, cargo storage, movement areas (helipads, truck loading areas, etc), and other critical relief operations within the current TIA perimeter fence (Figure 17). However, any and all operations that can be supported outside of the airport perimeter fence should be considered to decrease the potential incursion of actions in the AOA. This includes the use of the golf course adjacent to the existing TIA facility. This will also reduce the number of potential airport safety issues that may arise, as facilities will be more spread out allowing increased safe passage from the various operating areas outlined in the draft emergency operations land-use plan.

Airport capacity is summarized by the ability to offload aircraft, move the cargo from the AOA, and distribute it away from the airfield property. It is clearly understood that aircraft may play a role in multiple operations, such as delivery to the airport (ex. C-130 Hercules cargo airplanes), and then pickup and delivery off the airport property (ex. CH-47 Chinook cargo helicopters). Each AOA requires the same factors to assure safety and then capacity. In this instance, capacity is specifically tied to the movement of cargo from the delivery aircraft, to an area that is clear of the delivery AOA, and then to the pickup point. The links between these operations are usually ground vehicles of various types.

The layout of an AOA for each purpose must be addressed in the airfield emergency response plan with pre-designated roads, storage yards, and other mobility and egress issues identified. Storage must be more than 200 ft (61 m) from the centerline of the runway (max height is 8 ft [2.4 m]), outside of jet intake or engine blast ranges, and at least 1,000 yards (914 m) away from the ASR and Very High Frequency Omni-Directional Radio Range (VOR) to prevent operational and/or safety issues (Figure 17).
The impact of not having these issues addressed before an emergency occurs can lead to significant inefficiency, such as what was seen at the recent Haiti earthquake response. Transportation and logistical issues will dominate the ability to manage cargo and will usually determine the airport capacity.

Figure 17 - TIA DRAFT Emergency Operations Land-Use Plan
The requirements for the various relief operations must be identified and verified with the potential organizations expecting to support the disaster operations (ex. World Food Programme or U.S. Government). These requirements are used to evaluate the ability of TIA, CAAN, and the Nepal Army to meet these needs and determine if the current plan is effective. Without reasonable requirements, we can never determine if the airport capacity represents an adequate and reliable source. TIA, CAAN, and the Nepal Army need to collaboratively engage these potential aid organizations and partner nations as soon as possible so that their requirements can be included in a final emergency operation land-use plan for TIA.

Capacity could also be increased by adding integrated voice switches and installing a standalone Remote Transmitter and Receiver (RTR) in the International Terminal. The RTR needs climate control (HVAC), so its facilities could be used to store other critical response equipment (ex. portable transmitters and receivers [PET 2000 radios], spare electronic parts, etc). Additionally, high value recovery supplies would include chain link fence parts, cold mix asphalt (emulsion or cut back), and high strength quick setting cement. These recovery supplies need to be stored near the airfield where they can be expeditiously accessed and used in an emergency situation.

The following factors influence the total airport capacity at TIA.

A. Runway:

Minimum runway length for the design aircraft (C-130) at the altitude of TIA is 6,200ft (1,900 meters). For a C-130 Hercules and CH-47 Chinook, TIA can currently support an average of 40 operations per hour on their runway in most weather conditions.

The critical limitation of the TIA runway is the taxiway not extending to the end of the runway. Aircraft have to enter the runway, taxi to the end, turn around and then take off which requires a significant amount of additional time on the runway. This could be a limiting factor based on the turn-around (ability to unload, service and return aircraft to the runway for departure) rate of the aircraft.

B. Taxiways:

Taxiways and turn offs allow the aircraft to depart the runway and proceed to the ramps where they park and are serviced. If no turn offs or taxiways are available, then only one aircraft at a time can land, be serviced (off loaded), and then take off.

C. Ramps:

Ramps are areas for aircraft to park and be serviced. Services include off-loading, fueling, engine-starting, push back (tugs), reloading, etc.

D. Approach Control:

High Altitude Area Control (En Route in U.S.) manages aircraft between airports, and Terminal Approach Control (TRACON in U.S.) controls the transition from high altitude to/from the airport. In a large-scale
earthquake, both control systems will be lost, since they are located in the International Terminal and rely on remote locations to communicate with the pilots. With advanced planning agreements, these services can be backed up and provided regionally until they are recovered locally.

E. Airport Surveillance Radar (ASR)

The TIA ASR is critical to optimizing runway operations at all times and will significantly decrease capacity if it is damaged or destroyed. Plans must be created to rapidly repair or replace the ASR. The structural retrofitting measures outlined in Section 3 should be followed.

F. Aerodrome Traffic Control

The Aerodrome Traffic Control, or Air Traffic Control, manages landing/takeoff clearances, ground control of the runway, taxiways, and ramp.

G. Weather Conditions

TIA has a Category I (one) Instrument Landing Capability (ILC) when Instrument Flight Rules (IFR) are required, which indicates minimal adverse effects from weather. When Instrument Flight Rules (IFR) are not required, then Visual Flight Rules (VFR) apply. Helicopters can approach and depart from the airport without using the runway. This allows operations in conjunction with fixed wing aircraft using the runway. It would be possible to have dual helicopter approaches (each side of the runway), with fixed wing aircraft using the runway (Figure 17). Under VFR rules, this could allow up to 120 operations an hour (40 per approach and departure route) during an emergency in Nepal.

When ILS conditions exist, every aircraft has to use the runway approach and departure. Therefore, the total operations would drop to 40 per hour. This doesn’t appear to be a significant threat, but must be taken into account in the detailed design.

H. Security

The Airport Operating Area (AOA), which is everything inside the airport perimeter fence, must be secure from animals and personnel. This is to prevent accidents, which will severely restrict and hamper operations. The first security priority will be to repair the airport fence, and then remove all non-essential personnel from the AOA. Passenger and cargo screening will not be necessary until outbound flights are resumed.

I. Cargo

If all of TIA’s current cargo capacity was available, then they may be able (under normal conditions) to meet the food supply requirements outlined in Section 4.2.4. The earthquake will eliminate almost all normal conditions (ex. no road transportation to/ from the airport, damaged equipment, etc). Therefore, there is a reduced chance that TIA would be able to support relief operations without significant preparation and outside support.
Based on the field assessments that took place at the CMEP Seismic Vulnerability Procedures Workshop, the following risk categories have been generated for airport capacity at TIA.

Table 3 – Airport Capacity Risk Assessment

<table>
<thead>
<tr>
<th>Expected impact to Capacity</th>
<th>Probability</th>
<th>Severity</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Runway</td>
<td>L</td>
<td>H</td>
<td>M</td>
</tr>
<tr>
<td>Taxiways</td>
<td>L</td>
<td>H</td>
<td>M</td>
</tr>
<tr>
<td>Ramps</td>
<td>L</td>
<td>H</td>
<td>M</td>
</tr>
<tr>
<td>Approach/Departure Control</td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Airport Surveillance Radar (ASR)</td>
<td>L</td>
<td>H</td>
<td>M</td>
</tr>
<tr>
<td>Aerodrome Traffic Control</td>
<td>M</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Weather Conditions/ILS</td>
<td>L</td>
<td>M</td>
<td>L</td>
</tr>
<tr>
<td>Security</td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Cargo</td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
</tbody>
</table>

To summarize, aircraft parking and cargo management will be the limiting factors to airport capacity. This includes ground-based vehicles to move and manage cargo, with a goal of four (4) hours from airplane touchdown (C-130 Hercules) to take-off for the delivery of emergency relief supplies.

4.2.4 Airport Throughput

A 2007 World Health Organization (WHO) newsletter\(^1\) indicated that, “approximately 40,000 deaths, 95,000 injuries, and 600,000-900,000 homeless could be expected” if a catastrophic earthquake were to occur in the Kathmandu Valley. Using these numbers as an approximate estimate, we can derive throughput estimates for TIA during an emergency situation.

- Roughly 4,000 metric tons (MT) of food and water, or 1,000 MT of just food, would be required per day. The airport currently supports about 533 MT per day, and can support about 860 MT per day at its maximum capacity.\(^2\)

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\(^1\) [http://www.searo.who.int/LinkFiles/Advocacy_Efforts_Nepal_strengthenes_health_sector_capacity_to_deal_with__earthquakes_Aug07.pdf](http://www.searo.who.int/LinkFiles/Advocacy_Efforts_Nepal_strengthenes_health_sector_capacity_to_deal_with__earthquakes_Aug07.pdf)

In order to determine the throughput estimates above, the C-130 Hercules, C-47 Chinook helicopter, semi-truck, and 200-bed hospital were used for all design calculations. The load capacity of these resources is:

- Semi-truck: 40,000 pounds or 20 tons (18.2 MT)
- Chinook C-47 Helicopter: 24,000 pounds or 12 tons (11 MT)
- C-130 Airplane: 35,000 pounds or 17.5 tons (16 MT)
- A 200 bed hospital requires a minimum of 3,000 square feet. An area of 4,225 square feet has been established for all “relief” camps and operations (65 ft x 65 ft or 19.8 m x 19.8 m)

The TIA emergency response throughout calculations are outlined below in Table 3. These approximations were derived using the best possible information provided by TIA, CAAN, and the Nepal Army. These values are subject to change depending on the current status of the airfield, and they should be verified by the Government of Nepal before official planning commences.

**Table 4 – TIA Throughput Calculations**

<table>
<thead>
<tr>
<th>Cargo required per day to support food only:</th>
</tr>
</thead>
<tbody>
<tr>
<td>o 900,000 persons * 2 pounds per person per day = 1.8 million pounds per day or 900 tons per day.</td>
</tr>
<tr>
<td>o <strong>900 tons / 17.5 tons per C-130 = 51 C-130 missions per day.</strong></td>
</tr>
<tr>
<td>- One C-130 may fly multiple missions per day.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cargo required per day to support water only:</th>
</tr>
</thead>
<tbody>
<tr>
<td>o 900,000 persons * 8 pounds per person per day = 7.2 million pounds per day or 3,600 tons per day.</td>
</tr>
<tr>
<td>o <strong>3,600 tons / 17.5 tons per C-130 = 206 C-130 missions per day.</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cargo to support 200 bed hospitals:</th>
</tr>
</thead>
<tbody>
<tr>
<td>o Assume 5 days to construct one hospital and cargo is needed evenly over the 5 day period: 40 Missions per 200 bed Hospital = <strong>40/5 = 8 Missions per day per Hospital.</strong></td>
</tr>
<tr>
<td>o Assume 10 total hospitals</td>
</tr>
<tr>
<td>o There will be no Medical Evacuations (MEDIVAC) to other locations for this scenario.</td>
</tr>
<tr>
<td>o Assume two are being built, starting at Day 3 to completion of all 10.</td>
</tr>
<tr>
<td>o So <strong>16 Missions per day for 25 days.</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cargo per day:</th>
</tr>
</thead>
<tbody>
<tr>
<td>o With a 4-hour turn around, each parking slot can be used six (6) times per day.</td>
</tr>
<tr>
<td>o Each C-130 carries 22.5 tons, so each parking slot can support 135 tons per day.</td>
</tr>
<tr>
<td>o Currently, TIA has nine (9) slots available for large aircraft.</td>
</tr>
<tr>
<td>o <strong>9 * 6 = 54 C-130 missions per day or 1,215 tons per day.</strong></td>
</tr>
<tr>
<td>o Assume an aircraft (airplane or helicopter) must take off to create a parking slot for the next aircraft.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Air Operations per hour:</th>
</tr>
</thead>
<tbody>
<tr>
<td>o When Visual Flight Rules (VFR) conditions exist:</td>
</tr>
<tr>
<td>- The runway can support approximately 40 operations per hour. That would be 20 take offs and 20 landings or any combination that totals 40.</td>
</tr>
</tbody>
</table>
Helicopters will not require use of the runway and can run concurrently. Assume 40 per hour as a design number, it will probably exceed that.

Using an east and west helicopter approach and departure system, TIA can nominally support 40 Helicopter Operations on the East Approach, 40 on the West Approach and 40 Fixed Wing in the Runway for a total of 120 operation an hour (about 60 take offs and landings)

- When Instrument Flight Rules (IFR) exist:
  - All Aircraft must use the runway exclusively.
  - The runway can still support about 40 operations an hour.
  - Total operations drop from 120 to 40 per hour.

### 4.3 TIA Strengths, Weaknesses, Opportunities, & Threats (SWOT)

**Strengths:**

- International Civil Aviation Organization (ICAO) Standards require TIA to be at a heightened state of readiness and redundancy to maintain and sustain the safety of air and ground operations.
- TIA demonstrates a commitment to safety and compliance with ICAO Standards.
- TIA technicians and engineers demonstrated pride and ownership of their facilities and equipment. This indicates the facilities are prepared to withstand a disaster and that the first persons responding are able and willing to perform the work necessary.
- TIA handles large amounts of traffic and cargo yearly:
  - Passenger handling Capacity:
    - 1350/hr International
    - 350/hr Domestic
  - Cargo Handling Capacity:
    - 10,200 square meters or 16,000 MT per month

**Weaknesses:**

- Aviation risk focuses on airport and air operations. These do not account for community disaster recovery plans, such as those that are necessary for responding to an earthquake.
- TIA will be the short-term, sole source for relief in Nepal due to the likely loss of roads and bridges (Section 5).

**Opportunities:**

- Actions can be taken to increase the probability of assets being available to provide relief support.
- Facilities and equipment can be added that would significantly increase operational and recovery capability such as an integrated voice switch (if not currently present), a remote
transmitter and receiver site, and a storage area with critical recovery supplies such as cold mix asphalt, gravel, etc.

Threats:

- The lack of a unified planning system, integrated reporting, and planning will force critical planning and decision-making during the crisis recovery. This leads to errors and costly adjustments while trying to conduct a massive relief operation.
- The integrated aviation system requires initial and recurring training to assure proficiency. Technology and procedural methods need to be properly designed, implemented, and maintained before the disaster occurs.
- TIA has limitations that reduce recurring functions, such as training. This reduces the number of personnel who can be brought in to supplement staffing if the trained persons are not available.

4.4 References

In order to calculate throughput, land-use, and other airfield operation requirements, the following references were compiled.

4.4.1 Tribhuvan International Airport Profile

- Elevation: 4,390 ft or 1,338 m (MSL)
- Runway Designation: 02/20
- Runway Dimension: 10,000 ft. x 150 ft (3.048 m x 45.7 m)
- Runway Surface Strength: 54 F/A/W/T
- Aircraft Handling Capacity: International – Nine (9) medium and wide body aircraft; Domestic - 15 small aircraft
  Passenger Handling Capacity: 1,350/hr International; 350/hr Domestic
  Cargo Handling Capacity: 10,200 square meters or 16,000 MT
- Fire Fighting Category: Cat VIII
- Service: Air Traffic Control Service (Aerodrome Control, Approach Control, and Area Control)

4.4.2 C-130 Hercules Airplane³

Length: C-130E/H/J: 97 feet, 9 inches (29.3 meters); C-130I-30: 112 feet, 9 inches (34.69 meters)
Height: 38 feet, 10 inches (11.9 meters)
Wingspan: 132 feet, 7 inches (39.7 meters)

Cargo Compartment:
C-130E/H/J: length, 40 feet (12.31 meters); width, 119 inches (3.12 meters); height, 9 feet (2.74 meters).
Rear ramp: length, 123 inches (3.12 meters); width, 119 inches (3.02 meters)

C-130J-30: length, 55 feet (16.9 meters); width, 119 inches (3.12 meters); height, 9 feet (2.74 meters).
Rear ramp: length, 123 inches (3.12 meters); width, 119 inches (3.02 meters)

**Maximum Allowable Payload:**
- C-130E, 42,000 pounds (19,090 kilograms)
- C-130H, 42,000 pounds (19,090 kilograms)
- C-130J, 42,000 pounds (19,090 kilograms)
- C-130J-30, 44,000 (19,958 kilograms)

**Maximum Normal Payload:**
- C-130E, 36,500 pounds (16,590 kilograms)
- C-130H, 36,500 pounds (16,590 kilograms)
- C-130J, 34,000 pounds (15,422 kilograms)
- C-130J-30, 36,000 pounds (16,329 kilograms)

4.4.3 CH-47F Chinook Helicopter

- Useful Load: 24,000 lbs. (10,886 kg)

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4 http://www.boeing.com/rotorcraft/military/ch47d/index.htm

**Figure 18 - CH-47F Chinook Helicopter Dimensions**
4.4.4 Military Airfield Operation Area Layouts and Details

![Figure 19 - Notional Combat Aviation Brigade Support Area Helicopter Layout](image)

<table>
<thead>
<tr>
<th>Aircraft Type</th>
<th>Area per Aircraft (square meters/yards)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-130</td>
<td>3,913.632 square meters (4,280 square yards)</td>
</tr>
<tr>
<td>C-5A</td>
<td>11,384.28 square meters (12,450 square yards)</td>
</tr>
<tr>
<td>C-17</td>
<td>10,287 square meters (11,250 square yards)</td>
</tr>
</tbody>
</table>

**Table 6 – Helipad Dimensional Criteria**

<table>
<thead>
<tr>
<th>Clear zone</th>
<th>Length</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>121.92 m (400 ft)</td>
<td>Hover points, VFR and standard IFR helipads, begins at the end of the primary zone.</td>
</tr>
<tr>
<td></td>
<td>251.46 m (825 ft)</td>
<td>IFR same direction ingress/egress</td>
</tr>
</tbody>
</table>

---

Width | Corresponds to primary surface width. Center clear zone area width on extended center of the pad.
---|---
45.72 m (150 ft) | Limited use helipads and hover points
91.44 m (300 ft) | Standard VFR helipad and VFR helipad same direction ingress/egress
228.6 m (750 ft) | Standard IFR

<table>
<thead>
<tr>
<th>Grades of clear zone (any direction)</th>
<th>Max 5.0%</th>
<th>Area to be free of obstructions. Rough grade and turf required.</th>
</tr>
</thead>
</table>

4.4.5 Airfield Material Handling Equipment

The following airfield material-handling equipment is recommended at TIA for emergency operations. The necessary number of each piece of equipment is still to be determined.

- Conveyer Belts
- Forklifts
- Trolleys
- Containers
- Ladders
- Buses

- High Loaders
- Pallets
- Dollies
- Tracers
- Pushback Vehicles
- Generators
5. BRIDGE RECOMMENDATIONS

5.1 Summary

Four (4) bridges were studied for seismic vulnerability. Plans were provided for three (3) of these structures and recommendations have been made for each. The fourth structure did not have plans so a conservative approach was assumed. In general, the structures lacked seismic detailing that is required to provide a ductile behavior. The philosophy taken by AASHTO is to permit a structure to behave in a nonlinear fashion; however, it shall not fail. This is known as “life safety”. The structures that were assessed each had some form of vulnerable components (Table 7) that would not allow a ductile behavior, but rather a sudden and unacceptable brittle failure.

<table>
<thead>
<tr>
<th>Bridge</th>
<th>Condition</th>
<th>Measures Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Bridge (#1)</td>
<td>Retrofit Required</td>
<td>Jacketing, Reduction of stopper capacity, reconstruct approach retaining walls</td>
</tr>
<tr>
<td>Jaributi Bridge (#2)</td>
<td>Retrofit Required</td>
<td>Capacity protect pile cap</td>
</tr>
<tr>
<td>Bhimsengola Bridge (#3)</td>
<td>Retrofit Required</td>
<td>Base isolation</td>
</tr>
<tr>
<td>Sinamangal Old</td>
<td>Under Construction</td>
<td>Correct the seismic details</td>
</tr>
<tr>
<td>Banewsor Road Bridge (#4)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.2 Seismic Vulnerability Procedures Workshop

The first event in this two week series focused on seismic vulnerability assessment procedures. Subject Matter Experts (SMEs) conducted a five day sharing of information and technology. This time period focused sharing with the Nepalese, the seismic practices, guidelines, procedures, and methods for performing seismic design, assessments, and retrofit measures as required by the American Association of State and Highway Transportation Officials (AASHTO). The class materials included use of the American Association of State of Highway Transportation Officials AASHTO LRFD Bridge Design Specifications, AASHTO Guide Specifications for LRFD Seismic Bridge Design, and the FHWA Seismic Retrofitting Manual for Highway Bridges.

The focus of the “Bridge Team” was placed on lessons learned from recent earthquakes, seismic hazard analysis, seismic bridge design code requirements, force-based design philosophy, displacement based design philosophy, design detail requirements, and seismic retrofitting strategies.

SEISMIC VULNERABILITY BRIDGE FIELD ASSESSMENTS

The second event in this two week series was to put to practice the lessons learned from the class room. It shared with the Nepalese Engineers seismic vulnerability assessment strategies of retrofitting bridges in the Kathmandu Valley. The initial strategy was to put a seismic vulnerability assessment on each bridge.
5.3 Seismic Design Philosophy

The design philosophy for seismic behavior of bridges is that no structure shall fail or seriously injure any person. The structure shall perform in a ductile manner with no sudden or brittle failures shall occur. Also, if the structure is considered critical, essential vehicles shall be able to utilize them.

Behavior that is not permitted is shown in Figures 20 & 21 where unseating from simple spans and inadequate seat length. Shear failures due to inadequate lateral steel in plastic hinge zones have also occurred. Figures 22 & 23 illustrate rebar pullout and buckling of longitudinal reinforcement. The AASHTO Specifications are very prescriptive in detailing requirements to prevent such failures.
Figure 252 - Rebar Pullout

Figure 26 - Buckling of Longitudinal Reinforcement
When retrofitting a structure, there are typically two means to satisfy the philosophy of seismic behavior. These are to “increase” the capacity or to “decrease” the demand. That is to make elements stronger, more ductile, or additional seat length. To reduce the demand is to isolate certain elements so inertial loads to not reach that element. Each method has its merits and disadvantages.

5.4 Field Assessment

Originally, when the field assessment was established, the intent was to assess critical structures that provide a life line between Kathmandu and the airport. Four bridges were randomly selected by the Nepal Department of Roads and USAID. The first is a newly constructed structure, but not open to traffic at this time. The second and third bridges carry significant traffic and may be considered critical. The fourth was closed to traffic and a replacement is being constructed.

In order to establish a retrofit program, critical structures must be established and those considered high priority in a retrofit program. This is performed as outlined in the “Seismic Retrofitting Manual for Highway Structures”, Chapter 1 and is a function of many variables such as providing life safety, major economic impact, local emergency plan, and anticipated service life. Structures that are considered exempt include a bridge with less than fifteen (15) years of service life remaining, temporary, or closed to traffic and does not cross active roads, or waterways.

In the event of an emergency and since the rivers flow is often very minimum, it could be possible to quickly construct a detour as shown in Figure 24.

Before this temporary measure can be considered, however, the material must be accessible following an earthquake. It is understood that stockpiles for other material will be located outside of the city.
During high flow, a hydraulic engineer should be consulted to determine the required size of the culvert opening.

5.4.1 New Bridge (#1)

The “New Bridge” is a newly constructed structure that is not open to vehicular traffic. However, access is available for pedestrians and an occasional vehicle. The superstructure consists of four spans each being 21.7 m simple spans. The structure is 8.0 m wide (O-O) and has two 1.0 m sidewalks. It has three T-Beam girders with multiple cross girders.

The substructure consists of single column piers 1.8 m feet in diameter founded on pile caps with 20 piles each being 0.5 m in diameter and 19.8 m in length. The abutments are walls 1.3 m thick with stone masonry approach gravity retaining walls filled with stone rubble. There are 25 piles each being 22.9 m in length.

There is a 50 mm expansion joint at each abutment and a 3.0 m approach slab. Two anchor bolts 35 mm are provided at one end of each girder Figures 25 thru 30 provide photos as seen on site.

![Figure 25 - Elevation View](image-url)
Figure 26 - Diaphragms at Bearings and Diaphragms

Figure 27 - Six foot Diameter Pier with Shear Keys
Figure 28 - Shear Keys & Pier

Figure 29 - View of Deck
Figure 30 - Masonry Approach Gravity Retaining Walls
A) PIER EVALUATION

While reviewing the construction plans for the pier, it is observed that seismic consideration was made in the design. The longitudinal reinforcing steel extends through the entire footing and cap with no spliced “starter bars”. Splices are not placed in the longitudinal steel. Also, the lateral ties extend into the footing, cap and plastic hinge zone as shown in Figure 31 and Figure 32.

Figure 31 - Typical Pier

Figure 32 - Typical Pier Cross Section
However, as shown in Figure 33, the ties have a minimum lap length of 250 mm for a #10 reinforcing bar. While this length is sufficient for a Class “A” splice (top bar), it must have bars with a 135 degree hook with an extension of not less than 75 mm or 6 diameters in order to confine the core concrete following spalling of the outer shell. The minimum size shall be a #13 for the longitudinal steel of #20.

![Figure 33 - Typical Transverse Hoop](image)

Since the lateral ties will unwind with the onset of spalling, they are only effective to a concrete strain of 0.003 and the column must remain elastic to prevent failure. It is noticed that there are several other detailing concerns that will also contribute to a column failure if yielding should occur. These are not calculated since the splice alone will contribute to failure. These items are confinement over the full length of the plastic hinge.

Two checks will be made to ensure the column remains in the elastic range of stresses. The first will assume the anchor bolts will not fail and the full seismic load can transfer to the substructure. The second check assumes the anchor bolts will fail and only the maximum force of the bolt capacity is transferred to the substructure.

Conventionally, an overstrength plastic moment must be applied to the footing to ensure no failure of the footing occurs prior to plastic hinging. However, since a plastic hinge cannot form, the total elastic moment will be applied to the footing to check for capacity.

Determine Pier Capacity:

Weight:
Figure 34 - Cross Section of Superstructure

Area\(_1\) := \([250\cdot(2.37.5)]\cdot2\)
Area\(_2\) := \([1225\cdot(150 + 50) + 100\cdot1225 + \frac{1}{2}\cdot1225\cdot250]\)\cdot2
Area\(_3\) := \(\left(\frac{1}{2}\cdot200\cdot200\right)\cdot4\)
Area\(_4\) := 400\cdot1400\cdot3

\[
\text{Area}_{\text{super}} := \left(\sum_{n = 1}^{5} \text{Area}_n\right) \cdot \frac{1}{25.4^2\cdot144}
\]

\[
\text{diaphragm} := 1000\cdot250\cdot2460\cdot14
\]

\[
\text{super weight} := \left(\text{Area}_{\text{super}} \cdot \frac{21700}{25.4\cdot12}\right) \cdot 15 + \left(\frac{\text{Area}_6}{25.4^2\cdot144} \cdot \frac{21700}{25.4\cdot12}\right) \cdot 0.025 + \frac{\text{diaphragm}}{25.4^3\cdot12^3} \cdot 15
\]

Substructure

\[
\text{hammerhead} := \frac{800\cdot6200\cdot1800 + 2\cdot\frac{1}{2}\cdot500\cdot5300\cdot1800}{25.4^3\cdot12^3} \cdot 0.15
\]

\[
\text{column} := \left(\pi\cdot900\cdot\frac{6100}{2} \cdot 0.15\right) \cdot 25.4^3\cdot12^3
\]

\[
\text{shearkey} := (437.5\cdot500\cdot1500) \cdot \frac{0.15}{25.4^3\cdot12^3} \cdot 2
\]

Area\(_1\) = 3.75 \times 10^4 \text{ mm}^2
Area\(_2\) = 1.041 \times 10^6 \text{ mm}^2
Area\(_3\) = 8 \times 10^4 \text{ mm}^2
Area\(_4\) = 1.68 \times 10^6 \text{ mm}^2
Area\(_5\) = 1.11 \times 10^6 \text{ mm}^2
Area\(_6\) = 2.775 \times 10^5 \text{ mm}^2

Area_{\text{super}} = 42.504 \text{ ft}^2
\]

\[
\text{diaphragm} = 8.61 \times 10^9 \text{ mm}^2
\]

\[
\text{super weight} = 504.831 \text{ kip}
\]

\[
\text{hammerhead} = 72.561 \text{ kip}
\]

\[
\text{column} = 41.113 \text{ kip}
\]

\[
\text{shearkey} = 3.476 \text{ kip}
\]
The Resulted Axial Force-Bending Moment Interaction Data

CIRCULAR SECTION, Diameter= 70.866

<table>
<thead>
<tr>
<th>MOMENT</th>
<th>AXIAL LOAD</th>
<th>CURVATURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>82704.2</td>
<td>1458</td>
<td>0.00005572</td>
</tr>
<tr>
<td>78175.07</td>
<td>1192.99</td>
<td>0.00005439</td>
</tr>
<tr>
<td>73477.52</td>
<td>945.8</td>
<td>0.00005306</td>
</tr>
<tr>
<td>68639.18</td>
<td>697.67</td>
<td>0.00005174</td>
</tr>
<tr>
<td>67138</td>
<td>622 linear interpolation for axial load</td>
<td></td>
</tr>
<tr>
<td>63693.48</td>
<td>450.09</td>
<td>0.00005041</td>
</tr>
<tr>
<td>58689.78</td>
<td>204.71</td>
<td>0.00004908</td>
</tr>
<tr>
<td>53673.67</td>
<td>-36.78</td>
<td>0.00004776</td>
</tr>
</tbody>
</table>
Longitudinal Moment=315888 kip-inch >> 67138 k-in at axial load=622 kip. The column fails since plastic hinging is not possible with any lateral confining steel as shown in Figure 35.

Check maximum forces 32 mm diam. anchor bolts can transfer to the substructure in shear. Assuming an A36 anchor bolt, the shear capacity is 34.9 kips per bolt or 209 kips per pier.

Check forces transferred from anchor bolts:

\[ F_{\text{bolt}} = 209 \text{ kip} \]
\[ M_{\text{max}} = F_{\text{bolt}} \times 24.27 \times 12 \]

At an axial load of 622 kip, the moment capacity is 67138 K-in < Mmax=60869 kip-in   OK. It is anticipated the anchor bolts will fail which will protect the piers from entering the inelastic regions from bending. Since the column does not fail the ties should still provide shear capacity.
Check shear capacity of #3 @ 200 mm spacing
\[ n := 2 \]
\[ A_{sp} := .11 \]
\[ f_y := 60 \]
\[ D' := 65.3 \]
\[ s := 7.87 \]
\[ V_s := \frac{\pi}{2} \left( \frac{n A_{sp} f_y D'}{s} \right) \]

Concrete capacity in shear
\[ A_e := 0.8 \pi \cdot 70.87^2 \]
\[ V_c := 0.032 \cdot 3 \left[ 1 + \frac{622}{2 (\pi \cdot 70.87^2)} \right] \sqrt{3} \]
\[ V_e := V_c \cdot A_e \]
\[ V_u := 0.9 (V_s + V_c) \]

Shear capacity is satisfied for force the anchor bolts can transfer to the pier.

Assuming the anchor bolts do fail, check seat length required

**Seat Length Required**

\[ L_{span} := 68.9 \text{ ft} \]
\[ \text{Height} := 24 \text{ ft} \]
\[ B := 26.25 \text{ ft} \]
\[ N_{seat} := \left[ 4 + 0.02 L_{span} + 0.08 \cdot \text{Height} + 1.1 \sqrt{\text{Height} \cdot \left( \frac{1}{2} \frac{B}{L_{span}} \right)^2} \right] \]

\[ \Delta_{long} := \frac{F_{bolt}}{\text{stiffness} \cdot \frac{1}{12}} \]

\[ N_{seat} = 14.073 \text{ in} \]
\[ \Delta_{long} = 0.7 \text{ in} \]

Gap does not close
Figure 36 - CL Bearing to end of Girder

Seat length available = N = 900 mm – 25 mm = 34 in  OK >> 14 in

Figure 37 - 50 mm expansion joint
B) TRANSVERSE DIRECTION

Similar to the longitudinal direction, check if the shear key will fuse prior to failure of the substructure. Assume concrete was placed on a second pour with no roughened surface.

Shear key capacity-Transverse direction

Consider 40 #6 that must shear- Use Shear Friction Concept

\[
\begin{align*}
A_6 &= 0.44 \text{ in}^2 \\
c_c &= 0.075 \text{ ksi} \quad \text{cohesion of concrete} \\
\mu &= .6 \quad \text{friction} \\
A_{cv} &= 1500 \frac{500}{25.4^2} \\
A_{sf} &= A_6 \cdot 40 \\
f_y &= 60 \text{ ksi} \\
P_c &= 0 \\
V_n &= c_c \cdot A_{cv} + \mu \left( A_{sf} \cdot f_y + P_c \right) \\
V_n &= 720.788 \text{ kip} \\
K_1 &= .2 \\
f_c &= 3 \text{ ksi} \\
K_2 &= .8 \\
V_{ni} &= K_1 \cdot f_c \cdot A_{cv} \quad \text{Controls----------} \quad V_{ni} = 697.501 \text{ kip} \\
V_{n2} &= K_2 \cdot A_{cv} \quad \hspace{1cm} V_{n2} = 930.002 \text{ kip} \\
V_u &= 347.463 \text{ kip} \quad \text{NG}
\end{align*}
\]
Since the shear capacity of the shear key (stopper) is greater than the column, failure will occur in the column by both shear and moment due to a transverse seismic event. Retrofit will be required to keep this structure in service.

C) PIER RETROFIT MEASURES

It has been shown that the pier does not have the capacity to resist the anticipated seismic demand. In addition, the confining reinforcement is not detailed sufficiently to develop a plastic hinge. For this reason, a suggested retrofit scheme is to allow the anchor bolts to fail in order to “capacity protect” the substructure from a longitudinal event. Since the seat length is satisfactory, the superstructure can be “isolated” from the substructure. As a precautionary measure, it is suggested that cable restrainers be provided with ample slack to prevent engagement to the piers until just prior to the girders falling of the support. Alternative measures would be to install a device as shown in Figure 39 to restrain the superstructure prior to falling off the support.

![Figure 39 - Bumper Block](image)

However, in the transverse direction, the shear keys have significant strength to transfer the full seismic load to the substructure. A simple retrofit would be to limit the capacity of the shear key to match the capacity of the pier. In a seismic event, if the key did fail, it is doubtful the superstructure would fall off the pier cap due to the redundancy of the superstructure and number of diaphragms. However, there may be restricted access to the structure until repairs are made. If the capacity of the shear key is reduced so they fail prior to the pier becoming inelastic, an alternate scheme would be to use base isolation. This would prevent the inertial forces from the superstructure to transmit to the substructure.

A better retrofit scheme to consider would be wrapping the pier with fiber reinforcing or placing a steel casing to enhance ductility by providing confinement, improve shear capacity, and improve moment capacity. This would allow the structure to yield and still perform inelastically.
D) APPROACH/RETAINING WALLS

While assessing the structure, time was also spent to evaluate the approach retaining walls. These masonry walls are approximately 20 feet in height with a base of 6 feet. Typically gravity walls have performed well in seismic events. However, it is noted that when walls have sharp corners, extreme stress can occur and poor performance is expected.

Observation of the cracking which has occurred prior to any event is concerning. Only a rough analysis was performed since inadequate information is available. Using the Mononobe Okabe procedure to calculate lateral loads, a factor of safety for overturning is approximately 0.4. This indicates the wall will fail. More important to note, since the Mononobe Okabe procedure breaks down with high accelerations, only 0.4g was used to determine the factor of safety. This structure may experience accelerations of 0.6g

Reconstruction of the retaining walls to provide stability to external seismic forces should be considered.

E) CONCLUSION

Retrofit measures in the longitudinal direction are available with a minimum of expense; however, a lateral earthquake does present problems for the stability of the structure. It is suggested a confinement measures be placed on the column to satisfy the forces imposed and to provide ductility in the structure or to provide base isolation so the substructure remains elastic.

Even if the structure is retrofitted, failure of the approaches will prevent access to the structure and threaten the life of people living at the base of the walls. Reconstruction of the retaining walls may be the only option to prevent failure. Consultation with a qualified geotechnical engineer should be made for additional advice on retrofit of the approaches.

5.4.2 Jaributi Bridge (#2)

The Jaributi Bridge is a three span concrete structure with each span being 16.3 m in length (Figures 40 & 41). The total width is 12.5 m. The substructure consists of three columns 900 mm in diameter founded on a pile cap which connects to three 1200 mm diameter drilled shafts.

There are sufficient confining hoops in the column spaced at 150 mm. Although this spacing is greater than permitted by AASHTO, it should provide limited confinement to allow a ductile behavior. The ties have adequate seismic hooks to prevent unraveling following onset of spalling.

A) SUBSTRUCTURE

One location of concern is the column to drilled shaft connection. There is not adequate splice length to transfer loads between the drilled shaft and column steel. Since the splice is not adequate, the loads must transfer through the pile cap (Figures 41-45).
By inspection, in an extreme seismic event, the pile cap will develop a plastic hinge prior to the column yielding since it has less capacity than the column. This in turn will prevent loads from transferring to the drilled shaft rendering a failure. Also, the ties in the cap are spaced at 250 mm which will not provide confinement following a plastic hinge formation. The ties do not have seismic hooks and will fail with the onset of spalling.

One retrofit scheme would be to increase the capacity of the pile cap so it is “capacity protected” and the plastic hinge should occur in the column prior to the pile cap. This can be done by increasing the depth and placing new seismic ties with additional longitudinal reinforcing steel.

B) APPROACH SLAB

An approach slab 4 m in length and 250 mm in thickness is shown on the plans (Figure 46). This will aid in use of the structure following soil settlement. The connection of the slab appears to be adequate to transfer shear.

C) CONCLUSION

Seismic behavior appears to have been considered in the design. Plastic hinge locations do have confining reinforcement with proper seismic hooks and splices are avoided in critical locations. However, the load path from the column to the drilled shaft does not exist for an extreme event due to the pile cap failing. The pile cap in not capacity protected and lacks the capacity to permit hinging to form in the column.

*Figure 40 - Elevation View*
Figure 41 - Diaphragms & Pile Cap

Figure 42 - Column Reinforcing
Figure 43 - Pile Cap Reinforcing

Figure 44 - Pile Reinforcing
5.4. 3 Bhimsengola Bridge (#3)

The Bhimsengola Bridge consists of four simple spans carrying two lanes of traffic and two pedestrian sidewalks (Figure 47). The substructure consists of three columns on a pile cap which is connected to three drilled shafts. There is significant scour exposing the drilled shafts (Figure 48). Plans for the Bhimsengola Bridge are not available. Without knowing material properties, connection details and pile details, it is not possible to determine capacities and suggest retrofit schemes.

However, the structure type is very similar to the Jaributi Bridge and the problems noted with the pile cap are likely similar. Unlike the Jaributi Bridge, this structure is old and design practices at the time this structure was built did not provide seismic detailing.
A) RETROFIT MEASURES

Since the lateral stability of the piles is not known, and the deflection capacities of the substructure are questionable, a retrofit scheme to consider is to prevent the inertial loading from transferring to the substructure. The substructure must remain elastic. This can be achieved with base isolation. Significant deflections can be expected which will have to be carried by the abutments. Damage to the abutments can be expected with base isolation, but this is an acceptable damage since it is easily repaired.
5.4.4 Sinamangal Old Banewsor Road Bridge (#4)

This structure is in very poor condition due to ground settlement under the piers (Figures 49 and 50). It is not recommended for seismic retrofit since it is closed to vehicular traffic and is being replaced with a new structure (Figure 51).

Comments on the structure under construction are offered to make it perform in a ductile manner. The new structure is a two span, cast in place concrete T-beam superstructure. Each span is 20 meters long and has a width of 9.5 meters. The substructure is a single column with a diameter of 2 meters resting on a spread footing. The spread footing is cast on top of caissons with a diameter of 9.5 meters.

The abutment is a cantilever retaining wall 11.9 m high and an approach slab 3 meters in length. It also has a spread footing placed on a 9.5 m caisson.

A) SUBSTRUCTURE

The pier is placed on a concrete cap 1600 mm in thickness that will perform as a two way slab. (Figure 52) Some observations of the details is that there is no shear reinforcing steel in the slab. For this reason, if the column reaches its plastic moment capacity, it is possible the slab will fail in shear. Also, it is possible the slab will fail in bending prior to the column reaching the plastic moment capacity. The slab is not “capacity protected”.
Additional observations include details such as the longitudinal steel should have the hooks extend to the bottom mat of reinforcing steel and the hooks should be turned inwards. There are additional hoops placed in the plastic hinging zone, however they have no seismic hooks. As soon as the concrete begins to spall, the hoops will become ineffective and the column will not have confined concrete. This will render a brittle failure due to shear and/or bending. The hoops should also extend into the footing rather than terminate at the top of the footing.

B) SUPERSTRUCTURE

There is an approach slab which will offer access to the structure in the event settlement occurs. However, as shown in Figure 53, it is not clear how the approach slab is connected to the seat of the abutment. This connection should be sufficient to prevent the approach slab from falling off the seat.

The “stoppers” will offer restraint in the transverse direction. However, it is not clear what connection is restraining the superstructure in the longitudinal direction.

C) CONCLUSION

Since this structure is still under construction, retrofit schemes are not warranted. Instead, the details should be corrected to “capacity protect” the elements connecting to the pier and the reinforcing steel should be corrected to offer a ductile behavior as discussed above.
Figure 50 - Failed Bearing

Figure 51 - Elevation of New Structure
Figure 52 - View of Pier on foundation

Figure 53 - Approach Slab Connection