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GEODETIC CONSTRAINTS ON SLIP RATES OF LARGE CENTRAL ASIAN FAULTS

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EARTHQUAKE EMERGENCY EDUCATION IN DUSHANBE, TAJIKISTAN

By

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Geodetic constraints on slip rates of large Central Asian faults

Chairperson: Rebecca Bendick
Co-chair persons: Sarah J. Halvorson, Marc Hendrix

Abstract

Deformation throughout the Hindu Kush-Pamir-South Tien Shan section of the Alpine-Himalayan collision, as measured with GPS, shares characteristics in common with neighboring regions in Iran and Tibet, particularly the presence of numerous large faults with relatively low slip rates and large areas of distributed high elevation, suggesting similarities in regional dynamics. The convergence rate between India and Eurasia across this region is 27 ± 2 mm/yr, accommodated over more than 500,000 km^2 on thrust faulting north of the Peshawar Basin, the Hindu Kush, and within the Pamir (12 ± 3 mm/yr), and across the Alai-South Tien Shan (10 ± 4 mm/yr) with complementary slip on the Chaman-Gardiz (-5 ± 4 mm/yr) and Darvaz-Karakul (-12 ± 4 mm/yr) shear systems. The Pamir itself appears to deform through pure shear, with east-west extension of 11 ± 10 mm/yr comparable to the north-south shortening rate. By contrast, slip rates on the Herat and Talas-Ferghana faults are negligible.

Mohadjer, Solmaz, M.S., Autumn 2008 Geosciences

Earthquake Emergency Education in Dushanbe, Tajikistan

Chairperson: Rebecca Bendick
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Abstract

We developed a middle school earthquake science and hazards curriculum to promote earthquake awareness to students in the Central Asian country of Tajikistan. These materials include pre- and post-assessment activities, six directed inquiry-based science activities describing physical processes related to earthquakes, five interactive activities on earthquake hazards and mitigation strategies, and a codification art/literacy project. This curriculum was implemented with 43 middle school students in Dushanbe, Tajikistan in the winter of 2008. We examine the effectiveness of each curriculum component in communicating the causes, effects, and mitigation strategies associated with earthquakes to young people, and find significant improvements in seismic and earthquake hazards literacy as a result of the program.

1. Introduction

Broad, diffuse, and complex areas of active deformation often characterize zones of continental convergence. The India-Eurasia collision is no exception. The ongoing collision between the Indian subcontinent and Eurasia, since about 50 million years ago, at a rate of approximately 40 mm/yr, has resulted in a complex zone of deformation that spans as much as 3000 square kilometers between the stable portions of the Indian Shield to the south and the Siberian Platform to the north. The continued northward translation of the Indian plate with respect to the Eurasian plate has resulted not only in a broad orogenic zone with major fault systems, but also intense seismicity in the region. One of the most active intracontinental seismic zones occurs beneath the Pamir in Tajikistan, and underneath the Hindu Kush in northwest Pakistan, far northeast Afghanistan, and southern Tajikistan.

For this research, I use precise geodetic observations to estimate deformation rates for major active tectonic structures in the western end of the India-Eurasia collision zone, which includes the region of Central Asia. The research results yield an important contribution to seismic hazard assessment and planning efforts in the region, especially in demonstrating a need for earthquake science and hazard education in urban centers with high risk.

Thesis Objectives

The primary goals of my thesis work were to establish accurate present-day slip rates for several major faults and larger scale deformation rates across the region, and to identify or better quantify little-known regions of high strain with potential for large earthquakes. The results of my work are shown in the attached article (*Geodetic constraints on slip rates of large Central Asian faults*) submitted to *Geology*, a peer-reviewed scientific journal of the Geological Society of America.

A secondary goal of my thesis work was to develop a set of earthquake education materials that can be employed by scientists in Central Asia to reduce informational vulnerability, and to help engender collective cultures of prevention. The results of this effort are shown in the attached article (*Earthquake Emergency Education in Dushanbe, Tajikistan*) submitted to the *Journal of Geoscience Education,* a peer-reviewed international publication for geoscience education research.

Below I introduce the papers and the relationship between the two. I also discuss the methodologies employed to produce both scholarly papers.

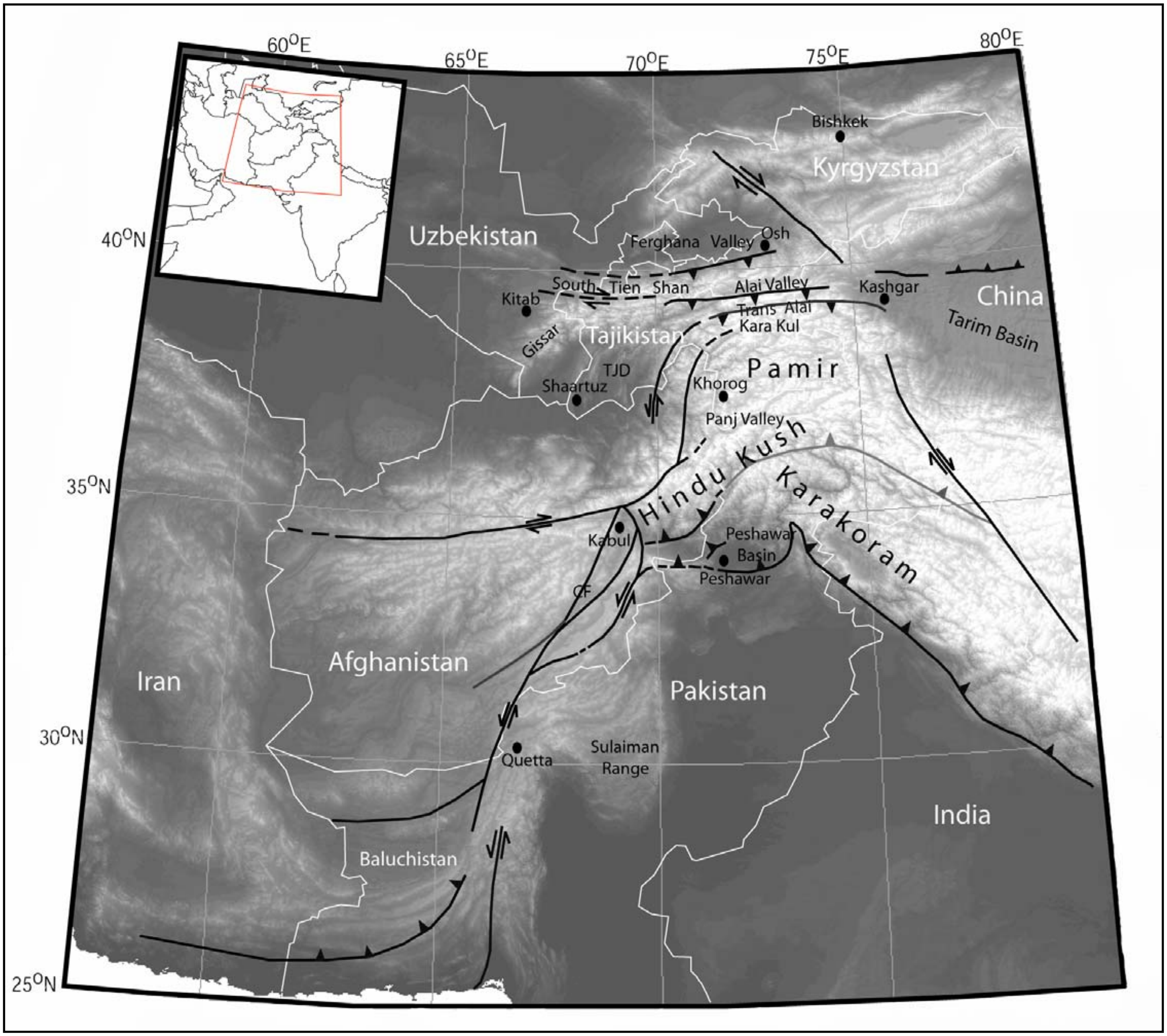

Figure 1-1. Location and tectonic setting of the study area.
Heavy black lines are major active faults, fine lines are inactive faults.
TJD: Tajik Depression, CF: Chaman Fault

Thrust faults
Strike-slip faults
Faults (approximate locations)
Major cities or towns

Research Motivations

Often described as a natural laboratory, the mountainous regions of Central Asia are an ideal place to study ongoing continent-continent collision. The western part of the India-Eurasia collision zone is characterized by a diverse range of structures and deformation styles. It includes a large transform, the Chaman fault system, possible pure shear strain in the main Pamir, crustal shortening and shear in the Hindu Kush-Southwest Pamir and across the Hindu Kush deep seismic zone, and crustal shortening in the Trans Alai region. The region is characterized by an intricate network of faults with different orientations, ages, and directions of movement. Due to limited field studies in this region, accurate Quaternary slip rates for most of these faults and geologic structures are generally unknown, poorly-constrained, and at times contradictory or unverified by follow-up studies.

Establishing accurate present-day slip rates for large structures in this region is critical both for understanding large-scale continental tectonics and for seismic hazard assessment. A fault's style of movement and likelihood of producing earthquakes is related to the rate of elastic strain stored in the fault system compared to the rate of energy release through displacement events, such as earthquakes or creep episodes. At large scales, the general pattern and rates of plate motions are known from Global Positioning System measurements; these motions are the fundamental sources of energy. At smaller scales, the detailed pattern and rates of deformation associated with individual faults and other major structures are poorly understood. In the study region, large active faults are often located at or near urban centers like Kabul and Dushanbe; both cities are highly vulnerable to earthquake disasters. As shown in "*Geodetic constraints on slip rates of large Central Asian faults*", the research results provide upper bounds on slip rates for major active structures and faults in the region. Combined with information about the past history of earthquakes on the structures, this information serves as the basis for developing earthquake forecasts.

Central Asia is also characterized by a lack of public access to science-based earthquake information. For many reasons, scientists have been unable to share vital earthquake hazards information with people. In many areas, the indigenous population is not aware of the steps it can take to mitigate hazards. As visiting scientists, we are in a unique position to raise the level of citizen scientific comprehension about earthquake hazards, thereby empowering and encouraging citizens to participate in the hazard mitigation process and to increase their chances of survival. To achieve this, I developed, implemented, and evaluated a set of earthquake education materials with middle school students in Tajikistan. The results of this effort are included in "*Earthquake emergency education in Dushanbe, Tajikistan".*

Research Methodology

Central Asian Geodetic Network- The surface of the earth is continually being deformed by tectonic processes. Surface displacements and deformation can be measured directly by geodetic techniques (such as leveling, triangulation, trilateration, radar interferometry).

In this research, I used Global Positioning System (GPS) geodesy to obtain precise measurements of position. With this method, horizontal displacements of crust can be obtained directly by measuring the positions of fixed sites/monuments. By re-measuring the position of each site (under similar conditions at different times), it is possible to estimate mean displacements over time (or velocities) for each of the sites.

In this study, sites are designed in order to maximize the contribution to velocity from tectonic processes and to minimize the contributions from other secular processes such as mass wasting or groundwater transport. Site selection of monuments on solid bedrock needs to be carefully examined to ensure that a "surface floater" rock (i.e. one not attached to bedrock) is avoided. In addition, each site must have a good sky view for GPS observations, and must also be accessible and secure. Each GPS site is equipped with a Trimble R7 receiver, a Trimble Zephyr Geodetic antenna mounted carefully on a stable bipod on 1-cm diameter stainless steel bolts set with industrial-grade epoxy into approximately 30-cm deep drilled bedrock holes, or into shorter drilled holes in reinforced concrete buildings (Figure 1-2). Each site is powered using a solar panel and battery. The receivers are programmed to record observations at a 30-second sampling rate. Important information (e.g., the height of the antenna, start and end time for data collection, and approximate location of the site) is documented at each site.

I installed and measured a Central Asian geodetic network during the summers of 2006 and 2007, and winter of 2008. This network contains three continuous sites in Tajikistan, one continuous site in southern Kyrgyzstan, and one campaign site in Afghanistan. These supplemented existing sites installed in western and southern Pakistan, northwestern India, western China, and two International GNSS Service (IGS) sites in Uzbekistan and Kyrgyzstan.

GAMIT: *Determining loosely constrained GPS positions*

For estimation of three-dimensional relative positions of sites and satellite orbits, I employed a comprehensive GPS analysis package called GAMIT. GAMIT uses the GPS broadcast carrier phase and pseudo range observables to estimate three-dimensional relative positions of ground stations and satellite orbits, atmospheric zenith delays, and Earth orientation parameters. It is composed of distinct modules, which perform the functions of preparing the raw data for processing, generating reference orbits for the satellites, computing residual observations and partial derivatives from a geometrical model, detecting outliers or breaks in the data, and performing a least squares analysis.

GAMIT uses pseudorange data in RINEX files to estimate site position calculated daily in a loosely constrained global reference frame. The global reference frame used in this study includes 14 IGS sites aside from the two IGS sites in Kyrgyzstan and Uzbekistan, which were treated as experimental rather than reference sites in my processing. The primary output of GAMIT is a loosely constrained solution (h-file) of parameter estimates and covariances.

GLOBK/GLORG: *Refining solutions and determining velocities*

Daily solution h-files are converted into binary h-files which can be passed to GLOBK for combination of data from multiple epochs to estimate a mean site position and velocity, and orbital and Earth-rotation parameters. To obtain a time series of site coordinates, GLOBK combines the binary h-files with global files from SOPAC for each year and day of data. The time series are plotted and examined for outliers. In this process, GLOBK imposes constraints on the coordinates of the IGS sites to define a Eurasia-fix reference frame using GLORG. GLOBK does this by using a Kalman filter which operates on covariance matrices and requires a non-infinite *a priori* constraint for each parameter estimated. Once outliers are identified and resolved, I use GLOBK to combine the daily h-files into bi-weekly h-files that represent estimates of site positions. To define a reference frame in this process, I use a standard file of coordinates and velocities for global reference sites (ITRF05) for initial position and velocity solutions of each site for each year. A product of the initial GLOBK combination run is a file of coordinates for all sites used in the study. In the final GLOBK run, this apriori file is used along with the ITRF05 to utilize the combined h-files as input to obtain a final time series and final estimates of site velocities for the entire period spanned by the study data.

Decomposing the velocities- Once site velocities have been determined, I identified the major structure(s) between a pair of sites. I then took the difference between the site velocities and used the mean strike of the relevant structure to decompose slip rates (parallel and normal to the strike). This method allowed for placement of upper bounds on fault slip rates.

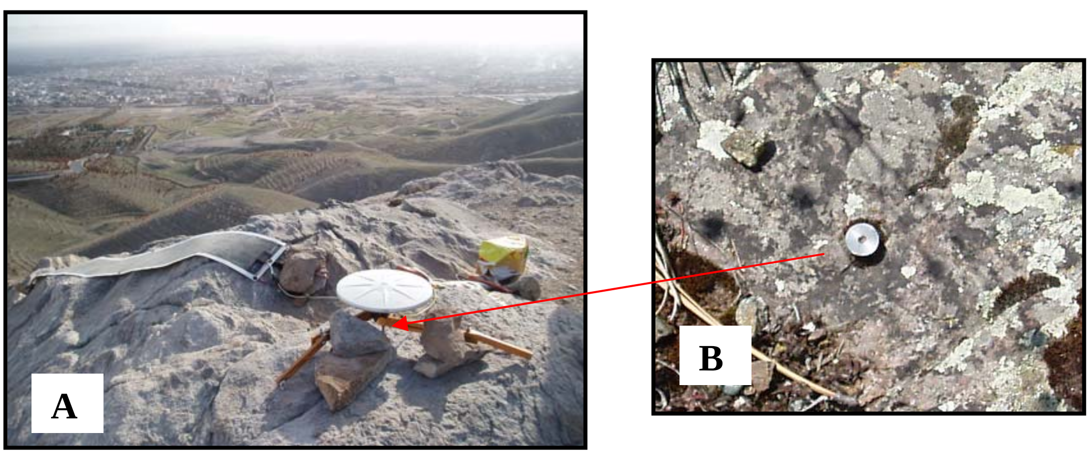

Figure 1-2. A campaign station in Herat, Afghanistan (a); 1-cm diameter stainless steel bolt (b)

Figure 1-3. A continuous station in Khorog, Tajikistan.

Earthquake Emergency Education: A *stepwise approach*

I developed an earthquake curriculum that includes pre- and post-assessment components, along with 6 science lessons, 5 hazards and mitigation lessons, and a codification activity. The lessons have been adapted from a variety of published and unpublished materials developed by geoscientists, science teachers, and aid and emergency agencies all around the world. The lessons are integrated, hands-on, and culturally sensitive. The curriculum is designed to take a stepwise approach to prepare students for earthquakes, with later lessons building on topics covered in earlier lessons. I assessed the effectiveness of the curriculum lessons by comparing pre- and post-assessment data.

Concluding Remarks

The geodetic results from this study offer useful information for seismic hazard assessment in a region with limited physical and economic resources for hazard mitigation. The stepwise approach to earthquake education with middle school students in Dushanbe has been demonstrated as an effective method for dissemination of scientific information with young people.

Geodetic constraints on slip rates of large Central Asian faults

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Abstract

Deformation throughout the Hindu Kush-Pamir-South Tien Shan section of the Alpine-Himalayan collision, as measured with GPS, shares characteristics in common with neighboring regions in Iran and Tibet, particularly the presence of numerous large faults with relatively low slip rates and large areas of distributed high elevation, suggesting similarities in regional dynamics. The convergence rate between India and Eurasia across this region is 27 ± 2 mm/yr, accommodated over more than 500,000 km^2 on thrust faulting north of the Peshawar Basin, the Hindu Kush, and within the Pamir (12 ± 3 mm/yr), and across the Alai-South Tien Shan (10 ± 4 mm/yr) with complementary slip on the Chaman-Gardiz (-5 ± 4 mm/yr) and Darvaz-Karakul (-12 ± 4 mm/yr) shear systems. The Pamir itself appears to deform through pure shear, with east-west extension of 11 ± 10 mm/yr comparable to the north-south shortening rate. By contrast, slip rates on the Herat and Talas-Ferghana faults are negligible.

1. Introduction

Accurate slip rates for large structures around plate boundaries using precise GPS geodesy constrains both hypothesized mechanics of large-scale continental dynamics and regional assessments of seismic hazard. The region of Central Asia encompassing Pakistan, Afghanistan, Tajikistan, and Kyrgyzstan both serves as an example of intracontinetal deformation, and imposes boundary conditions on the more thoroughly studied Tibetan Plateau to the east. Due to limited field studies and sparse GPS coverage in this region, however, neither accurate present-day slip rates for several important faults nor larger scale deformation rates across the region are currently known. Previously published estimates, where they do exist, are poorly constrained, spatially limited, and at times contradictory or unverified by follow-up studies (Figure 2-1). At the same time, seismological data indicate significant moment release throughout the area, including within the poorly understood Hindu Kush seismic zone.

The main goals of this paper are to describe the overall large-scale pattern of surface velocity in the study area and to place constraints where possible on the slip rates of major mapped faults. We also identify regions of measurable deformation where important faults (or other deformation processes) remain unidentified.

2. Methods

We installed a network of GPS points in the study area defined by the coordinates 30^o to 44^oN latitude and 60^o to 76^oE longitude (Figure 2-2) including eastern Afghanistan, Tajikistan, northwestern Pakistan, western Baluchistan, and western Kyrgyzstan. Measurements at these sites are supplemented with observations from two IGS sites, KIT3 in Uzbekistan and POL2 in Kyrgyzstan. We also include the velocity of Kashgar reported in a Eurasia-fixed frame by Zhengkang Shen (personal communication, 2008) in order to estimate the rate of east-west extension across the Pamir. All of the sites with velocities reported here (Table 2-1) operate continuously and were installed on engineered monuments, with the exception of Kabul, which was occupied for 93 days in

2006 and 10 days in 2008, and Kashgar. The monumentation and instrumentation of the IGS sites are available directly from the IGS archives; the other sites are occupied with either Trimble netRS receivers or Trimble R7 receivers and Trimble Zephyr antennas on 1-cm diameter stainless steel bolts set with industrial-grade epoxy into approximately 30-cm deep drilled bedrock holes (MANM, SHTZ, OSHK, and GARM), or into shorter drilled holes in reinforced concrete buildings (QTAG, KCHI, and NCEG). KBUL is a 30-cm long threaded rod mounted on the roof of a reinforced concrete building. Data are recorded at 30-second intervals in all cases.

Site position estimates are calculated daily with the GAMIT software package (Herring et al., 2006) in a loosely constrained global reference frame including 14 IGS sites aside from POL2 and KIT3, which were treated as experimental rather than reference sites in our processing. The resulting time series are used to estimate site velocities in ITRF05 and a Eurasia-fixed reference frame using GLOBK (Herring et al., 2006) (Table 2-1). These time series and additional occupation information are provided in the Supplementary Information.

Finally, we estimated the parallel and normal slip rates on important regional structures by compiling regional fault maps from a wide range of sources (Ruleman et al., 2007; Ambraseys and Bilham, 2003; Burtman and Molnar, 1993; Wolfart and Wittekindt, 1980; Shareq and Chmyriov, 1977). Notably, several of these sources contain inconsistent locations, strikes, and even names of faults, especially where structures cross international boundaries. Where discrepancies occur, we used several strategies for reconciliation, including comparisons with digital topography (SRTM 3-second), ASTER and Landsat imagery, preference for positions and strikes from field expeditions over remote sensing, and preference for peer-reviewed international publications over regional journals and reports. Once mapped, we simply used the mean strike of the relevant structure between GPS site pairs to decompose slip rates (Table 2-2). As always with this method, we can provide only upper bounds on fault slip rate because we assume that the entire relative velocity between the two geodetic sites is accommodated on a single structure except where otherwise noted. An ongoing campaign GPS experiment associated with the permanent network reported here is expected to provide more detailed information in the future about the reasonableness of this assumption.

3. Results

Chaman Boundary System

Slip rates on the main trace of the Chaman Fault are not constrained by our geodetic network, since Kabul lies east of the fault, as are Quetta and Peshawar. The northern extension of the Chaman boundary, however, splays into a suite of large strike-slip faults, including the Gardiz Fault, which hosted a Mw=5.9 event on 5 October 2008, and the Mokur Fault, both with evidence for left-lateral displacement in Quaternary basin deposits (Ruleman et al., 2007). Previously measured geologic rates on the main Chaman Fault trace range from ~20-40 mm/yr (DeMets et al., 1990; Lawrence et al., 1992). No geologic slip rate estimates have been published for the Gardiz or Mokur splays; Ruleman et al. (2007) state evidence for right and left-lateral offsets on Quaternary deposits associated with movements on the Gardiz Fault (Figure 2-1).

The difference in velocities of GPS sites at Quetta and Kabul allow an upper bound of 5.2 ± 4 mm/yr of sinistral shear across the combined Gardiz and Mokur faults. The difference between Kabul and Peshawar velocities allows as much as 18.3 ± 3 mm/yr of total sinistral shear accommodated by the Gardiz-Mokur-Konar system with a thrust component on the Konar fault north of the Peshawar Basin. Kabul itself moves at 8.8 ± 2 mm/yr at N14ºE relative to stable Eurasia, suggesting active shortening across the ranges of northern Afghanistan.

Hindu Kush-Southwest Pamir

Quaternary faults mapped in this region include north to northwest-trending strike-slip faults that cut across older north- to northeast-trending thrust faults (Ruleman et al., 2007). Several active thrust faults have also been mapped in the region between the Peshawar Basin and the Panj Valley. The surface projection of the Hindu Kush deep seismic zone, whose relationship to surface kinematics and dynamics is controversial, also lies between the continuous sites in Peshawar and Khorog. No geological or paleoseismological estimates of total shortening or individual fault slip rates across this region are currently reported in the literature.

The relative velocity between Peshawar and Khorog places an upper bound on this total surface deformation within the Hindu Kush-Southwest Pamir Region. Net north-south shortening dominates the velocity field, at a rate of 12.3 ± 3 mm/yr. The velocity field also contains a component of 7.4 ± 3 mm/yr of sinistral shear on an east-west striking zone.

Darvaz-Karakul Fault

Offsets of Holocene and late Pleistocene landforms, especially early Holocene terraces and alluvial fans, give slip rates of 10-15 mm/yr (Kuchai and Trifonov, 1977; Trifonov, 1978, 1983) on the Darvaz-Karakul Fault. Except for an offset wall, these geologic rates rely on assigned ages that are based on correlations with features and deposits in the Tajik Depression, not quantitative measurements. The component of velocity between Khorog and Shaartuz parallel to the mean strike of the Darvaz Fault of N5ºE limits total sinistral shear on the fault to a maximum of 12.5 ± 4 mm/yr, consistent with the reported geologic rates.

Tajik Depression

The topography of the Tajik Depression is characterized by regularly spaced arcuate ranges, averaging ~ 1 km in maximum elevation, and ~ 400-500 m of relief. The length scale of range spacing along with regional geology suggest thin-skinned shortening with limited shear required by range curvature (Bernard et al., 2000; Burtman and Molnar, 1993), apparently above a weak salt layer as in the Sulaiman Ranges of Pakistan and the Zagros. These structures act in concert with Darvaz shear to accommodate partitioned E-W extension of the main Pamir into the Tajik Depression and northward displacement of the massif relative to Eurasia.

Reported evidence of late Quaternary strike-slip displacements along some of the faults in the Tajik Depression includes 90 m of offset of late Pleistocene terraces (Trifonov, 1978, 1983), displacement of 10-35 m of dry valleys since the late Pleistocene (Nikonov, 1970; Trifonov, 1983), and 15 m of offset in other Holocene landforms (Legler and Przhiyalgovskaya, 1979) (Figure 2-1). No total shortening rates for either the whole depression or individual ranges have been reported.

Relative velocities between Khorog and Shaartuz confirm slow shortening of 5.3 ± 3 mm/yr across most of the Depression; a small amount of additional shortening is indicated by the presence of low ranges extending into Uzbekistan to the west and a significant shortening rate of 6.7 ± 3 mm/yr between Shaartuz and Kitab, Uzbekistan. The latter rate may include active deformation in the southwest Gissar Range.

Pamir

Because our continuous network does not span the eastern Pamir, we also include a velocity for Kashgar in the western Tarim provided by Z. Shen (personal communication, 2008) to quantify east-west extension of the Pamir. The relative velocity between the westernmost Tarim and the site at Khorog indicates a maximum rate of 11.3 ± 10 mm/yr of east-west extension across the central Pamir. The uncertainty on this velocity is an upper bound calculated by adding the uncertainty for Kashgar to our uncertainty in defining a Eurasia-fixed frame. This allows for differences in the Eurasia-fixed reference frames reported here and used by Shen to estimate the velocity at Kashgar.

The total north-south shortening rate in the Pamir reported in the Pamir-Hindu Kush section above is comparable to this east-west extension rate, consistent with pure shear of the region. Combined with a paucity of mapped active faults within the Pamir (e.g., Strecker et al., 1995), this observation suggests dynamic similarities between the Pamir and the Tibetan Plateau, where differences in gravitational potential energy from that of surrounding regions and possibly low stiffness within the high-elevation region provide large contributions to the surface deformation field.

Trans-Alai

Reigber et al. (2001) report a geodetically estimated rate of 13 ± 4 mm/yr of shortening across the eastern end of the Alai Valley between Kara Kul and the Ferghana Valley. This rate is significantly higher than the archeologically estimated rate of 2-4 mm/yr (Nikonov et al., 1983) at the Alai Valley south of Kyzilsu River near 72^{o} E, and the geologically estimated lower bound on the rate of 6 mm/yr (Arrowsmith and Strecker, 1999) along the 50-km-long east-west striking central Main Pamir thrust (at the Syrinadjar fault zone). These latter rates, however, were estimated directly at the fault trace bounding the Alai Valley on its southern edge; so the difference between estimates is most likely due to additional strain in the northern Pamir south of the main Alai thrust and to convergence between the South Tien Shan and the Ferghana Valley.

GPS sites in Khorog and Osh provide an upper bound on total shortening in the combined Central Alai and northernmost Pamir of 10 ± 4 mm/yr, in agreement with previously reported rates.

Herat Fault

Geologic evidence exists both for and against present-day activity of the Herat Fault. Limited field studies suggest that at least the eastern part of the Herat Fault has not been very active since Miocene time (Tapponnier et al., 1981). The global Centroid Moment Tensor catalog does not contain any instrumentally recorded events on the Herat Fault

(Figure 2-1). We confirm this lack of active slip by observing a sinistral shear rate of 7 ± 4 mm/yr between Kabul and Shaartuz. This is the opposite sense of slip from geologic interpretations of Herat Fault displacement, suggesting that the displacement of Kabul relative to Eurasia is dominated by distributed deformation in northern Afghanistan and perhaps slip on the Chaman Fault system, rather than on the Herat Fault. Shortening between Kabul and Shaartuz occurs at 5.7 ± 2 mm/yr, consistent with small mapped thrust faults and topographic relief in northernmost Afghanistan west of the Hindu Kush.

Talas-Ferghana Fault

Reigber et al. (2001) do not directly estimate a slip rate on the Talas-Fergana Fault, but note large residuals in their estimate of rotation for a Ferghana Valley block relative to Eurasia. No teleseismic moment release on the Talas-Ferghana is recorded in the global Centroid Moment Tensor catalog (Figure 2-1), but the M~7.6 Chatkal earthquake of 1956 has been attributed to the Talas-Ferghana. Dextral slip parallel to the main trace of the Talas-Ferghana Fault between Osh and Bishkek occurs at 2 ± 1 mm/yr, significantly slower than the rate of 10 ± 2 mm/yr reported by Burtman et al. (1996).

4. Discussion

Qualitatively, the Pamir-Hindu Kush-Chaman system shares several features with the main Tibetan Plateau, including a large area of high elevation, subdued relief at high elevation, rapid incision by fluvial systems at the margins of the high plateau, and similar timing of collision, especially closure of the main Tethyan sutures (Ducea et al., 2003). Both regions seem to share characteristic distributions of large faults, too, with long, morphologically developed faults restricted to the margins of the highest elevation, rather than cutting through the centers of the plateaux. In Tibet, the high plateau is pervaded by a large number of shorter fault systems with limited total offset; the distribution of such features in the high Pamir is not yet determined, but fault plane solutions of earthquakes show normal faulting for both the Pamir and Tibet (Burtman and Molnar, 1993; Strecker et al., 1995).

There are also important differences between the two regions. The most important of these are length scale, with the Pamir an order of magnitude smaller in length than Tibet, and distribution of seismic moment release.

Quantitatively, the geodetic results reported here also suggest important similarities in surface velocities in both plateaux. In particular, the sum of slip rates on known individual large faults in the Pamir-Hindu Kush does not accommodate the total India-Eurasia convergence across the orogenic zone. This is also so for Tibet, where ~30-50% of total convergence is absorbed by continuous deformation (or large numbers of small faults with small relative displacements). Low slip rates on region-bounding faults in both systems appear to preclude rapid lateral translation of the interior. The Central Asian velocity field is consistent with pure shear deformation of the main Pamir plateau, further stimulating thin-skinned shortening westward into the Tajik Depression. As within Tibet, the overall pattern of surface velocity between cratonic Pakistan and far western stable Siberia is of gradual, distributed deceleration northward (hence diffuse strain) relative to a fixed Eurasian reference frame. We therefore hypothesize that these characteristic kinematics are indicators of fundamental differences between continental orogenesis and standard plate tectonics in oceanic lithosphere.

Some of the large regional faults do sustain sufficiently high slip rates to accrue substantial potential seismic moment over century time scales, especially the main Chaman Fault, the Darvaz-Karakul Fault, and the Alai Valley faults. These structures should be given high priority in seismic hazard assessment and paleoseismic investigation; they pose potential risks to large population centers.

Acknowledgements

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Figure Captions

Figure 2-1. Map of the study area showing localities where observations of Quaternary offsets (orange circles), geologic slip rates of known locality (orange stars), geologic slip rates of unknown locality along faults (orange rectangles), and geodetic slip rates of known locality (green stars) have been made. Locations of Quaternary offsets in Afghanistan are from Ruleman et al. (2007) and Wellman (1965); offsets in the Tajik Depression are from Legler and Przhiyalgovskaya (1979), Trifonov (1978, 1983), and Nikonov (1970). Total slip rate for the Chaman, Herat, and Talas-Ferghana faults are from Lawrence et al. (1992), Sborshchikov et al. (1981), and Burtman et al. (1996), respectively. Slip rate for the site in southern Pakistan is based on Nuvel-1 model (DeMets et al. 1990), the rates for Karakoram Fault and Main Frontal Thrust are from Brown et al. (2002) and Banerjee and Burgman (2002), respectively. The rate across the Tien Shan is based on GPS measurements from Abdrakhmatov et al. (1996). Deformation rates for the Darvaz Fault, the Garm, and Trans Alai regions are from Trifonov (1978, 1983), Konopaltsev (1971), Guseva (1986), Nikonov et al. (1983), and Arrowsmith and Strecker (1999) and Reigber et al. (2001), respectively. Abbreviations of fault names: TFF: Talas-Ferghana Fault, MAT: Main Alai Thrust, SGF: South Gissar Fault, DkF: Darvaz-Karakul Fault, CbF: Central Badakhshan Fault, HF: Herat Fault, CF: Chaman Fault, GF: Gardiz Fault, KoF: Konar Fault; ONF: Ornach-Nal Fault, MF: Mokur Fault, KF: Karakoram Fault, MBT: Main Boundary Thrust, MKT: Main Karakoram Thrust, MPT: Main Pamir Thrust. Focal mechanisms are from the global CMT catalog.

Figure 2-2. Locations of major active faults (heavy black lines), inactive faults (fine lines), and GPS velocity vectors with respect to Eurasia fixed reference frame. The orange vector is from Zhengkang Shen (personal communication, 2008). The error ellipses represent 95% confidence. Fault traces are modified from Ruleman *et al.* (2007), Ambraseys and Bilham (2003), Burtman and Molnar (1993), Wolfart and Wittekindt, (1980), and Shareq and Chmyriov (1977). Abbreviations of fault names: TFF: Talas-Ferghana Fault, MAT: Main Alai Thrust, SGF: South Gissar Fault, DkF: Darvaz-Karakul Fault, CbF: Central Badakhshan Fault, HF: Herat Fault, CF: Chaman Fault, GF: Gardiz Fault, KoF: Konar Fault; ONF: Ornach-Nal Fault, MF: Mokur Fault, KF: Karakoram Fault, MBT: Main Boundary Thrust, MKT: Main Karakoram Thrust, MPT: Main Pamir Thrust.

TABLE 2-1. STATION COORDINATES AND VELOCITIES

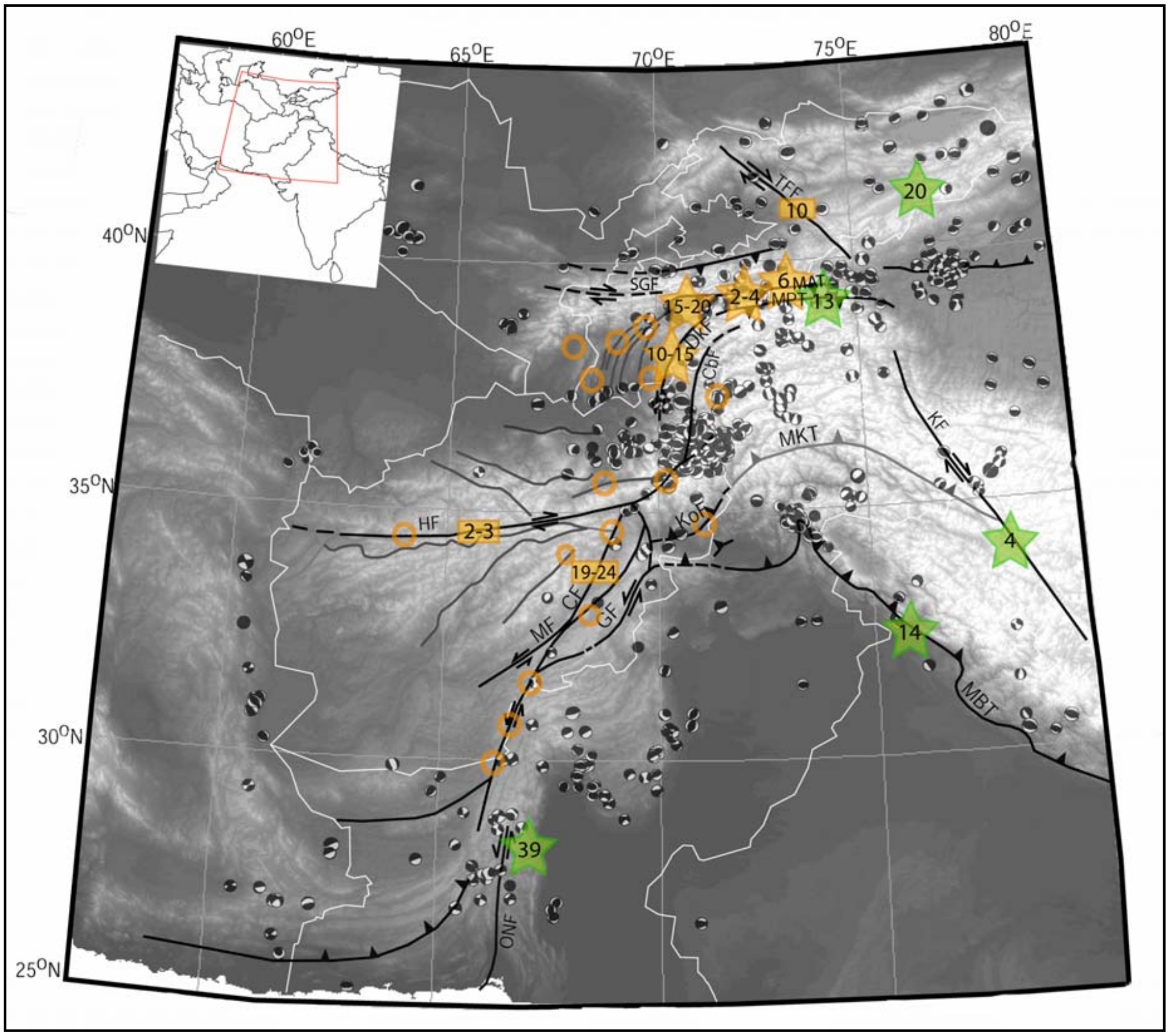
Site	Location	Longitude (deg.)	Latitude (deg.)	East mm/yr ITRF05	East mm/yr Eurasia	North mm/yr ITRF05	North mm/yr Eurasia
KBUL	Kabul	69.130	34.574	50.4 ± 1.5	2.1 ± 1.5	11.1 ± 1.5	8.6 ± 1.5
QTAG	Quetta	66.991	30.166	49.8 ± 1.4	1.5 ± 1.4	20.0 ± 1.5	16.6 ± 1.5
NCEG	Peshawar	71.487	34.004	47.4 ± 1.5	-0.8 ± 1.5	28.4 ± 1.5	26.9 ± 1.5
MANM	Khorog	71.680	37.542	39.8 ± 1.9	-8.3 ± 1.9	16.0 ± 1.9	14.6 ± 1.9
SHTZ	Shaartuz	68.123	37.562	43.8 ± 1.8	-4.1 ± 1.8	4.6 ± 1.8	1.7 ± 1.8
GARM	Garm	70.317	39.006	49.3 ± 1.9	1.4 ± 1.9	4.1 ± 1.9	2.2 ± 1.9
OSHK	Osh	72.777	40.530	47.8 ± 2.0	0.1 ± 2.0	5.6 ± 2.0	4.7 ± 2.0
KCHI	Karachi	67.113	24.931	56.5 ± 1.5	8.5 ± 1.5	28.6 ± 1.4	25.2 ± 1.4
IAOH	Hanle	78.973	32.779	50.6 ± 1.9	2.2 ± 1.9	15.1 ± 1.8	16.8 ± 1.8
RSCL	Leh	77.600	34.128	43.6 ± 1.6	-4.7 ± 1.6	17.8 ± 1.5	18.9 ± 1.5
KASH*	Kashgar	75.920	39.517	N.D.§	3.0 ± 1.5	N.D.	14.1 ± 1.5
KIT3	Kitab	66.885	39.135	50.1 ± 1.4	2.4 ± 1.4	1.8 ± 1.5	-1.7 ± 1.5
POL2	Bishkek	74.694	42.680	48.0 ± 1.6	0.6 ± 1.6	2.5 ± 1.5	2.4 ± 1.5

*Data for KASH is provided by Zhengkang Shen (personal communication, 2008)

§N.D. = no data.

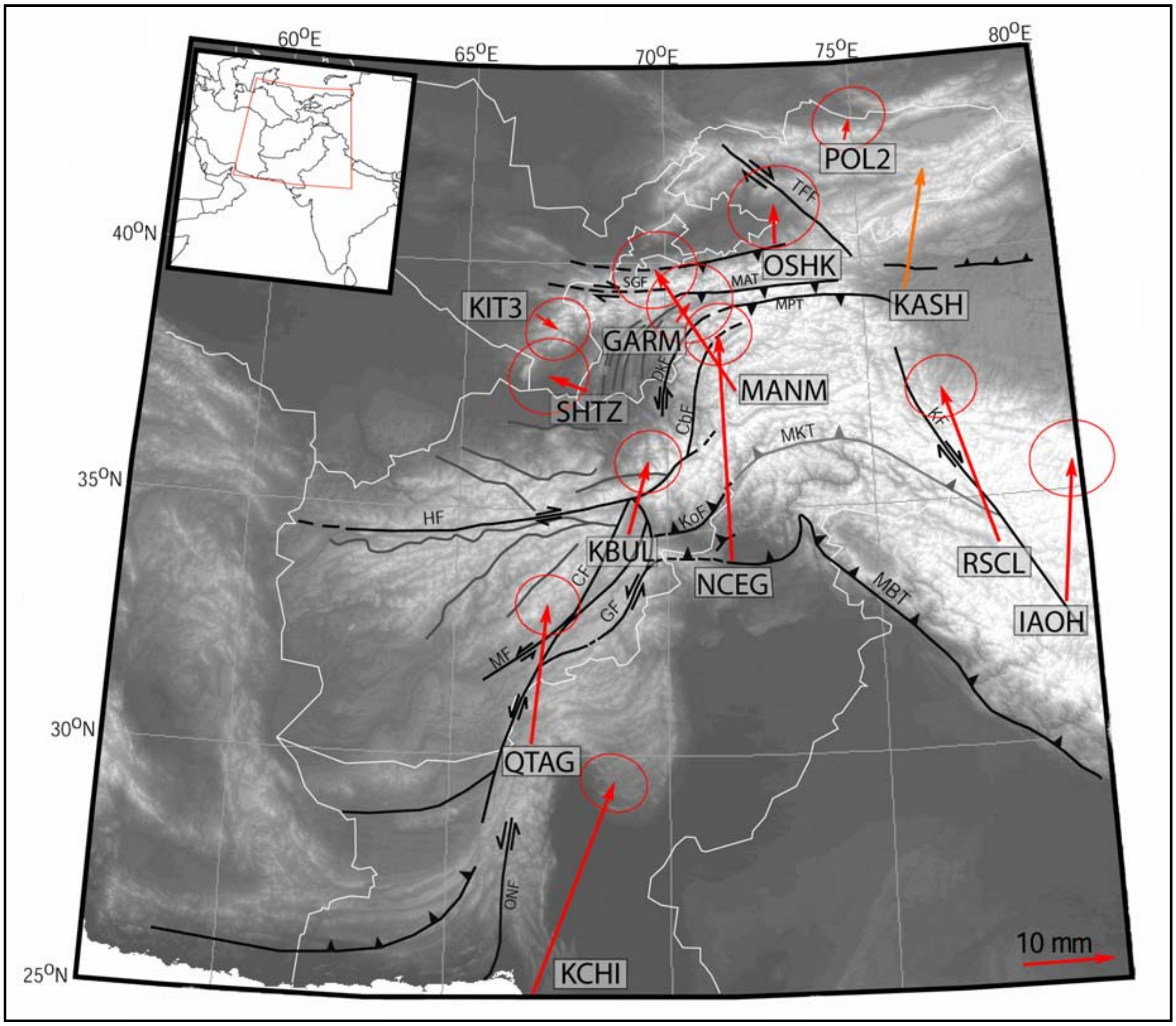
TABLE 2-2. SLIP RATE ESTIMATES FOR MAJOR STRUCTURES

Station Pair	Major Structure(s)	mm/yr ⊥	mm/yr ‖
QTAG-KBUL	Gardiz Fault	-6.1 ± 1	-5.2 ± 4
KBUL-NCEG	Konar Fault	18.3 ± 2	3.5 ± 4
NCEG-MANM	Hindu Kush	12.3 ± 3	-7.4 ± 3
MANM-SHTZ	Tajik Depression + Darvaz-Karakul Fault	5.3 ± 3	-12.5 ± 4
MANM-KASH	Pamir (east-west)	-11.3 ± 10	0.5 ± 10
MANM-OSHK	Trans Alai Belt	10 ± 4	8.4 ± 4
KBUL-SHTZ	Herat Fault	5.7 ± 2	-7.4 ± 4
OSHK-POL2	Talas-Ferghana Fault	1.3 ± 5	2.0 ± 1



60°E
65°E
70°E
75°E
80°E
40°N
35°N
30°N
25°N
TFF
10
20
SGF
15-20
2-4
6
MAT
MPT
13
10-15
DKF
ChF
MKT
KF
HF
2-3
KoF
19-24
4
CF
MF
GF
14
MBT
39
ONF

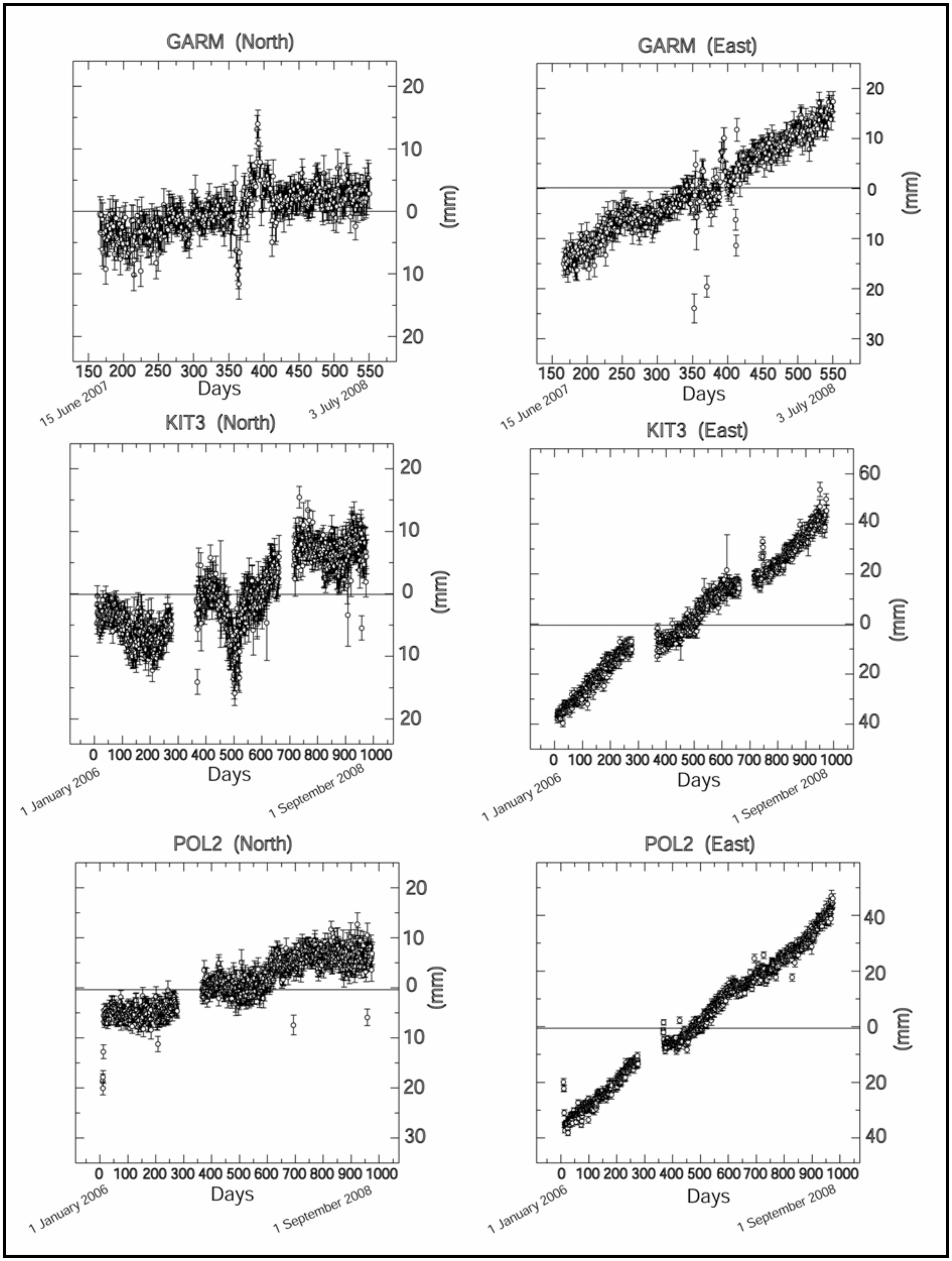
Figure 2-1



60°E
65°E
70°E
75°E
80°E
40°N
35°N
30°N
25°N
POL2
TFF
OSHK
KASH
KIT3
SGF
MAT
MPT
GARM
MANM
SHTZ
DKF
CbF
KF
MKT
HF
KoF
KBUL
NCEG
RSCL
MBT
CF
GF
IAOH
MF
QTAG
ONF
KCHI
10 mm

Figure 2-2

Supplementary Information: 2-1



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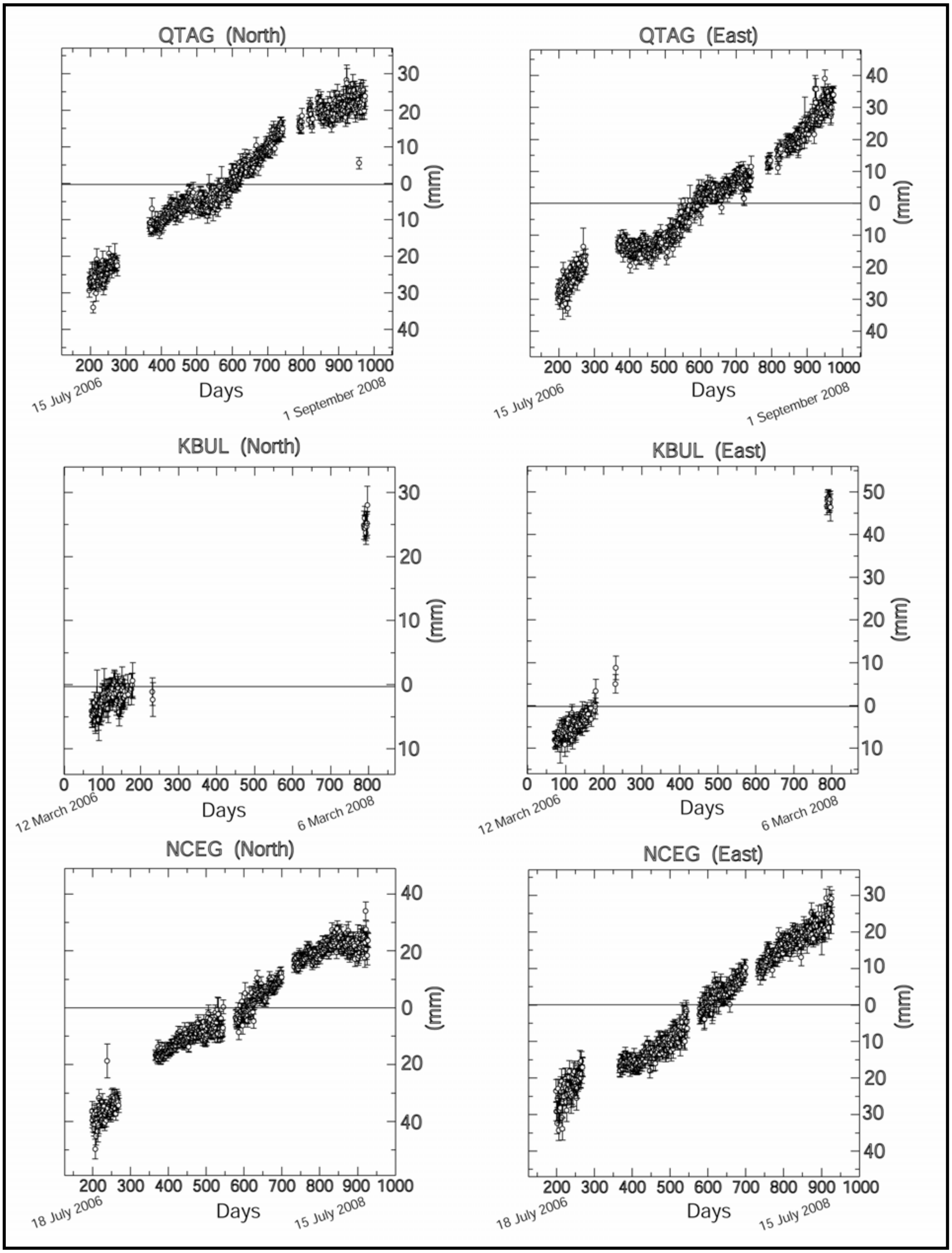
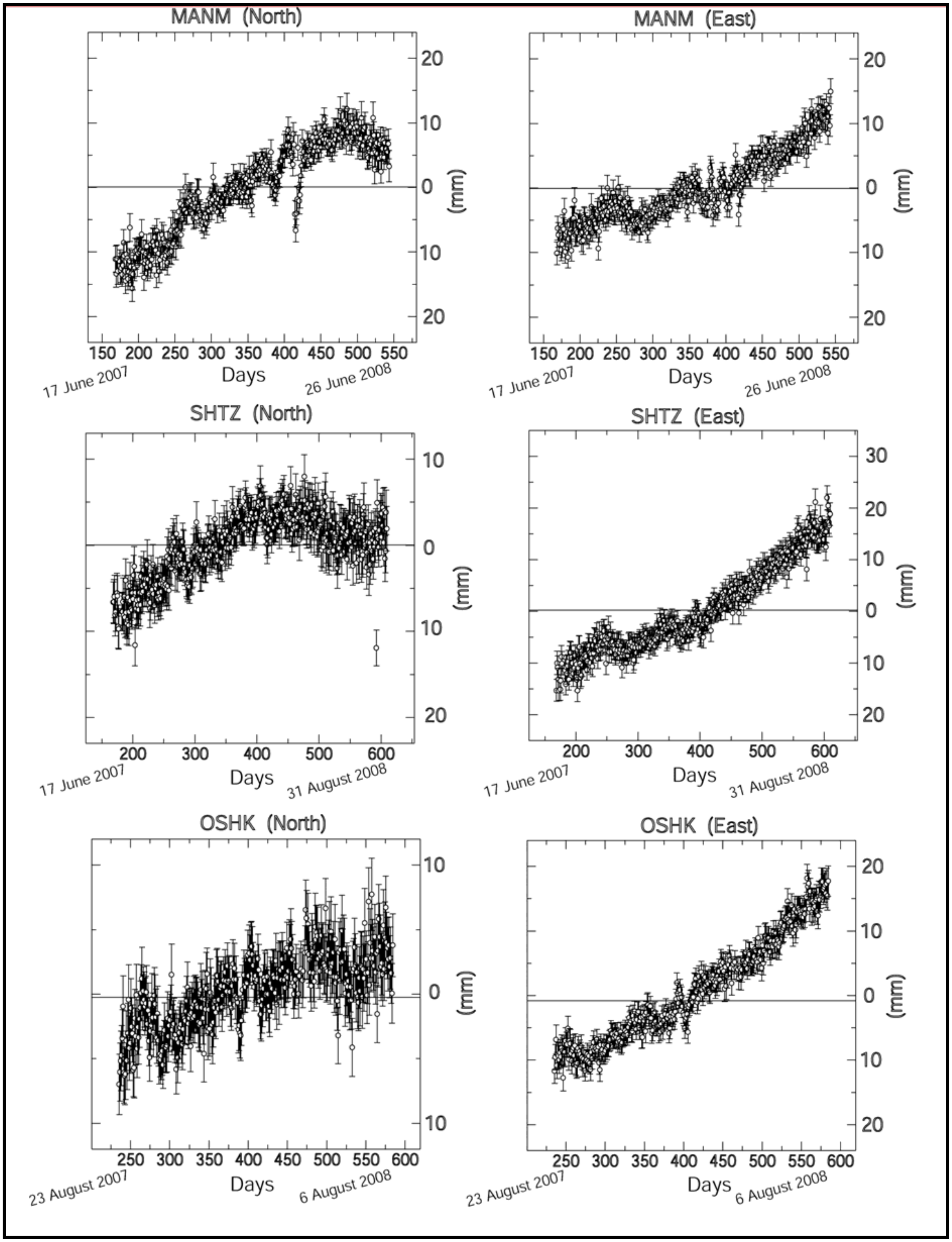


Supplementary Information: 2-3



Earthquake Emergency Education in Dushanbe, Tajikistan

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Abstract

We developed a middle school earthquake science and hazards curriculum to promote earthquake awareness to students in the Central Asian country of Tajikistan. These materials include pre- and post-assessment activities, six directed inquiry-based science activities describing physical processes related to earthquakes, five interactive activities on earthquake hazards and mitigation strategies, and a codification art/literacy project. This curriculum was implemented with 43 middle school students in Dushanbe, Tajikistan in the winter of 2008. We examine the effectiveness of each curriculum component in communicating the causes, effects, and mitigation strategies associated with earthquakes to young people, and find significant improvements in seismic and earthquake hazards literacy as a result of the program.

1. Introduction

The devastation the world witnessed following the 2008 Sichuan Earthquake, the 2005 Kashmir Earthquake, and the 2004 Southeast Asian Tsunami demonstrated the importance of communicating the causes, effects, and mitigation techniques for earthquakes in developing countries. In particular, systematic substandard school design and construction exacerbate risks to school-aged children (Revkin, 2008). Earthquake activity has been recognized as the most damaging hazard in Central Asia, especially in terms of casualties (Pusch, 2004; Eugster et al., 2004; King et al., 1999; Khalturin et al., 1997). The region is also characterized by a lack of public access to science-based earthquake hazard information (Halvorson and Hamilton, 2007). A form of what Degg and Homan (2005) refer to as "informational vulnerability" is evident throughout this region. In many areas, the indigenous population is not aware of the self-protective steps it can take to mitigate hazards.

"Informational vulnerability" is ultimately rooted in and perpetuated by lack of access to information (or ineffective dissemination methods) and a depressed regional economy. This vulnerability is often reinforced in situations where experts are unable to share information with the general public. For example, the Central Asian country of Tajikistan has both institutes dedicated to earthquake research and public school systems, yet neither group has the economic resources to promote earthquake hazard education. Without material support, there are very few interested, qualified individuals within the country who can help ensure that people are aware of their options when facing earthquake hazards. Short of addressing these financial limitations, visiting scientists are in a unique position to leverage academic resources to raise the level of citizens' scientific comprehension about earthquake hazards, thereby empowering and encouraging them to participate in the hazard mitigation process and to increase their chances of survival.

We have developed a set of curricular materials which can be employed by local and visiting scientists to reduce informational vulnerability and to help engender collective cultures of prevention. These materials are optimized for scientific content, ease of implementation, appropriateness to the targeted grade level and cultural sensitivity. The curriculum was field-tested and implemented with 43 middle school students in two public schools in Dushanbe, Tajikistan, in the winter of 2008. Below, we describe its components including a pre-assessment activity, six directed inquiry-based science activities on physical processes describing earthquakes, five interactive activities on earthquake hazards and mitigation strategies, a curriculum codification activity, and a post-assessment activity. We also demonstrate the effectiveness of the curriculum in communicating earthquake hazards to Tajik middle school students, based on a comparison of pre- and post-assessment data.

The primary objectives of this curriculum are as follows: (1) ensure that students understand and employ basic earthquake science terminology when discussing earthquakes and earthquake hazards; (2) encourage students to employ critical thinking skills when sharing and receiving earthquake-related information; (3) empower students to utilize all resources (public and private, individual and collective) to protect themselves and their communities from earthquake hazards; and (4) encourage an innate interest in earthquake hazards so that the benefits of the earthquake hazards curriculum outlive the workshop.

2. Curriculum Structure

This curriculum takes a stepwise approach to prepare students for earthquakes, with later lessons building on topics covered in earlier lessons (Figure 3-1). It introduces students to the fundamental scientific concepts behind earthquakes as well as earthquake hazards and mitigation techniques. The implemented lessons have been adapted from a variety of published and unpublished materials developed by geoscientists, science teachers and aid and emergency agencies all around the world. The lessons have also been adapted to include the latest, region-specific information, and to be responsive to the needs of Tajik students in culturally appropriate ways. Lessons and the codification activity can be downloaded or viewed at http://courses.teacherswithoutborders.org/emergency-education/earthquake-science/ and are included in the supplementary information accompanying this article. Table 3-1 summarizes the learning objectives of lessons and activities implemented in this curriculum.

Pre-assessment - The ultimate goals of the pre-assessment activity are to establish interpersonal relationships between the students and the educator, investigate students' preconceptions and perceptions of earthquakes and earthquake hazards, and allow for clear communication of the curriculum's key elements. The pre-assessment activity consists of one-on-one reciprocal interviews between the students and the educator. This allows students to voice their opinions and thoughts in a private environment where they are not going to be judged by their peers. In so doing, the assessment provides equal opportunity to students, regardless of the amount of pre-existing earthquake knowledge or the student's gender. This latter consideration is particularly important when working with Tajik students, as female Tajik students tend to not voice their opinions in the presence of male students. In the trial implementation, interviews took place during school period, were carried out a week prior to the start of the lessons in a classroom, and lasted approximately 10 minutes per student.

To meet the above objectives, each interview began with personal introductions between each student and the educator and the sharing of personal earthquake stories. Each student was then asked a series of open-ended questions about their experiences with recent earthquakes (e.g., Have you felt an earthquake before? Where were you when the ground started to shake? Were you alone? What was your immediate response? What damage did it cause? How did the shaking make you feel? Did anyone explain to you what was happening?). Students were also asked about whether they had considered making any particular immediate response to future earthquakes, based on their acquired experiences or knowledge. Students’ responses allowed the educator to gain insight into what gaps of knowledge most likely contribute to the students’ exposure to earthquake hazards. To assess each student’s level of Earth sciences knowledge, particularly their understanding of physical processes associated with earthquakes, and to make any necessary adjustments to the curriculum prior to its implementation, each student was asked about the Earth’s interior structure, mountain building processes and the causes of earthquakes. During the interviews, the educator explained to students the key elements and practicality of the curriculum, and invited students to raise questions and concerns related to the curriculum.

Earthquake Science Lessons **-** To understand earthquake hazards and to mitigate their effects, students must understand earthquakes and related physical processes. This component of the curriculum is designed to introduce students to fundamental scientific concepts of seismology. The primary objective of this component is to assist students with developing a scientific explanation for earthquakes. Turcotte and Schubert (2002, p. 339) describe earthquakes as follows:

“When a fault sticks, elastic energy accumulates in the rocks around the fault because of displacement at a distance. When stress around the fault reaches a critical value, the fault slips and an earthquake occurs. The elastic energy stored in the adjacent rock is partially dissipated as heat by friction on the fault and is partially radiated away as seismic energy.”

For students to be able to understand and comprehend the definition of an earthquake as provided by Turcotte and Schubert, a curriculum that addresses the following fundamental questions in a logical order, and with demonstrated connections between concepts, must be employed: (1) What do we mean by plate tectonics? (2) What happens near plate boundaries? (3) What are the different kinds of plate motions, and mechanisms driving them? (4) What are faults and how are they produced? (5) How and why can rocks be deformed? (6) How does faulting cause earthquakes? (7) What is seismic energy and how does it travel through the Earth? We implemented six science lesson plans (Table 3-1) with Tajik students, inviting them to explore the aforementioned questions. The lessons are integrated, hands-on, inquiry-based, and are ordered logically, re-introducing concepts and drawing connections between them as students proceed to work through the curriculum.

Earthquake Hazards and Mitigation Strategies **-** To prevent panic during earthquakes and to protect oneself against earthquake hazards before, during, and after an earthquake, an accurate understanding of the hazards, the physical processes producing them, and how earthquake damage can be mitigated, is critical. The primary objectives are to (1) create awareness about earthquake hazards; and (2) empower students to utilize all available resources to protect themselves and their communities from earthquake hazards.

To meet these objectives, we implemented five hazards classroom activities with Tajik students (Table 3-1). The activities were integrated and hands-on, with a primary focus on regional hazards and the mechanisms that produce them, particularly the hazards threatening the city of Dushanbe (i.e. structural collapse, landslides, and liquefaction). Relevant information (photographs, articles, eye witness accounts) that help to describe local and regional earthquake damage were incorporated into the activities. We also included examples of similar earthquake hazards and their effects on communities worldwide, describing earthquakes as universal phenomena that can be planned for through quantification, comprehension, and community action.

As part of the lessons, students conducted a safety assessment of their classrooms and home, and reported their findings to their families. Resources to reduce or remove all earthquake hazards are limited or non-existent in Dushanbe. Therefore, emphasis was placed on risk reduction through hazards identification and community awareness activities, including communication of the identified hazards to the appropriate local authorities.

Curriculum Codification Activity **-** Codification activities are a means of asking students to provide or invent a context that links curriculum concepts together. In the case of earthquake education, a codification activity should help students reinforce the concepts that make earthquake science, hazard awareness, and hazard prevention three aspects of a unified whole: earthquake safety. The codification activity adapted for this curriculum is a story writing activity originally developed at the University of Washington's Pipeline Project (http://www.washington.edu/uwired/pipeline/springbreak/), and is similar to the scrapbook exercise developed by Burnley (2004). This activity promotes reinforcement of concepts learned from previous lessons in a flexible and creative environment, and instills a sense of pride and accomplishment in the students as the curriculum is completed.

In this activity, students used information from previous lessons to write stories about individuals or communities affected by an earthquake. Students were encouraged to incorporate as much of the material covered in the curriculum as possible, but were left free to use personal experiences, cultural anecdotes, or invented characters or places to create the fundamental storyline. Students brainstormed, wrote, edited, illustrated, published and bound their stories into a single signature book, including a photograph of themselves along with a self-written ‘About the Author” section in their books (Figure 3-4). Publishing a book and recognizing the students as authors are more than simple reminders that the students have successfully finished the lessons. This sense of pride was clearly evident in students’ self-written author sections and in the presentation of their work to their peers and teachers at their school. To further emphasize the value of students’ written words, students were invited to place their books in their school’s library.

Post-assessment - To measure students’ performance, the effectiveness of the instructional methods, and to collect feedback for curriculum improvement, we conducted two guided focus group discussion sessions. The discussion sessions also provided a means for learning how students might have discussed topics covered by the curriculum amongst themselves. A total of 31 students out of the original 43 students participated in the discussions. Each discussion lasted for about 2 hours, and took place in a classroom two weeks after curriculum implementation. To draw out information from students regarding concepts learned throughout the curriculum, we asked students a series of questions. The discussion questions were nearly identical to the survey questions asked prior to the curriculum implementation.

3. Observations

Below, we summarize observational data collected from the pre- and post-assessment and the codification activities.

Pre-assessment Observations **–** The pre-assessment observation data are shown in three main categories: earthquake experience, response, and causes. Tables 3-2 and 3-3 summarize the data for the later two categories.

Earthquake Experience **-** All students had experienced at least one earthquake in their lifetime, with 26 percent of them having experienced earthquakes multiple times. Fifty-two percent of students claimed they were at school when they felt an earthquake; the rest were at home. One fourth of them expressed fear and panic when describing their experiences with earthquakes. Female students were more likely to convey their fear than their male counterparts.

Earthquake Response - Overall, most students provided no coherent response describing immediate actions that would help to ensure their safety during an earthquake (Table 3-2), despite having previously conducted earthquake drills at their schools. Fifty-six percent of students claimed to “escape” or “run away” when describing their actions during past earthquakes. As one student explained “We ran outside and stood under a tree so nothing could happen to us.” A significant portion of students (37 percent) exercised no action when experiencing an earthquake. One student explained “We stood where we were. God knows better. There’s nothing we could do,” but most students argued that the earthquake was too small and quick to cause them any harm. Only a small portion of students (7 percent) sought shelters inside the structures they were in. They claimed to have stood in the corners of the room where the walls converge or in door frames, or to have gone underneath a table.

When asked to list actions they think they should take during an earthquake in the future, almost 50 percent of students chose “going outside” over no action (25 percent) or taking shelter (25 percent). Overall, when describing appropriate responses to earthquakes, most students related the magnitude of an earthquake to the type of response they would take: “going outside” in case of a large earthquake and “staying inside” in case of a small earthquake.

The concept of pre-earthquake preparation was an unfamiliar topic to all students. When asked what they would do to prepare for an earthquake, most students provided suggestions in terms of an immediate response to an earthquake. Responses such as “I can take shelter somewhere during an earthquake until it’s over,” or “I’ll stay at the corner of the room next to the walls or go under a desk,” were most common. The question was rephrased to encourage students to think about long-term preparation. Students were asked to list the things they would do between now and next year if they are told there will be an earthquake next year. No student was able to respond to this question.

Causes of Earthquakes - When asked about the causes of earthquakes, 58 percent of students used a combination of disconnected scientific and non-scientific concepts and terminology in their answers (Table 3-3). About 39 percent of students mentioned upward movement of lava, formation of mountains, particularly volcanoes, but also stated that “dead bodies of people and animals” constitute lava. The majority of responses were similar to this response from a student: “The people who die, after many millions of years, come out of the Earth like lava and that causes an earthquake. A mountain appears in every place the Earth shakes." A noticeable portion of students (12 percent) listed "extraction of natural resources" as a cause of an earthquake with no elaboration while a small portion (7 percent) named floods, waves and avalanches as responsible for earthquakes. One student mentioned "earthquakes in the sea" and based his observation on television, listing Sri Lanka as an example of a place where this type of earthquake occurs.

Fourteen percent of students' responses were considered completely non-scientific. These responses included stories of animals such as cows, turtles, elephants, or fish, and how their motion results in earthquakes. A negligible portion of non-scientific answers included references to God. For instance, when asked what causes an earthquake, one student answered: "I don't know. It's either in God's hands, or I don't know." However, almost all students avoided claiming non-scientific answers as their own by making clear that the given opinions were public opinions, and that they reflect nothing about their personal views. When asked about their personal views, almost all students claimed opposition to public opinions and chose to answer the question by saying "I don't know."

Post-assessment Observations **–** Focus group discussions revealed three main observations: (1) most students employed basic earthquake science terminology when discussing earthquakes and earthquake hazards; (2) while most individual students lacked comprehensive understanding of scientific concepts related to earthquakes and earthquake hazards, through interaction with each other, they were able to connect scientific concepts to explain the mechanisms that produce earthquakes and earthquake hazards; and (3) a number of students claimed to have shared the knowledge gained through this curriculum with others, and to have taken small actions to reduce damage associated with earthquakes in their homes and school (e.g., putting together a family emergency kit, rearranging their rooms to make them safer, raising concerns with appropriate authorities about their safety during an earthquake).

The following sample group discussion demonstrates the first two observations mentioned above. In this discussion, students brainstormed ideas and connected scientific concepts together to generate an accurate scientific explanation for earthquakes. The concepts and terminology employed by students in this discussion are based on their observation of a fault model (built and operated in the “Earthquakes” lesson).

Moderator: *Who can explain how earthquakes happen?*

Student 4 and 10: *Because of plate tectonics.*

Student 4: *Aha, elastic accumulates! Pressure accumulates and this causes earthquakes.*

Student 4 and 5: *Energy, pressure.*

Moderator: *What kind of energy?*

All students*: Elastic!*

Student 14: *First very slowly, and then it becomes hard.*

Student 2 and 3: *It accumulates slowly, the energy, and then there’s a big earthquake.*

Student 1: *When there are forces acting on the Earth…tectonic forces…there’s friction in the Earth, elastic pressure accumulates and when it’s released, it results in an earthquake.*

Student 4: *Earthquakes occur because of plate tectonics, but what causes the plate tectonics?*

Student 3 asks Student 1: *What causes an earthquake?*

Student 1: *Because of the tectonic plates, when they move, there’s an earthquake.*

Student 14 asks Student1: *But what about the tectonic plates? How are they formed?*

Student 3 says to Student 1: *In Asia, there's the Indian tectonic plate and that's why there are earthquakes in this region. But what about other places with earthquakes?*

Student 4: *People ask us why earthquakes happen, and we say because of plate tectonics, then they ask us why does plate tectonics happen?*

In the discussion above, students not only answered the question raised by the moderator, but throughout the discussion they asked other fundamental scientific questions that were not discussed in the curriculum implementation (e.g., why does plate tectonics happen and how are tectonic plates formed?). This level of scientific inquiry demonstrates that students not only absorbed information during the lessons, but that they also developed an innate interest in physical processes related to earthquakes, and could use the acquired knowledge to ask specific, scientific questions. Students have also started to think critically when sharing and receiving earthquake information. One student explained her reaction to her neighbor when the neighbor told her that "there is a cow in the Earth that causes it to shake." "I told her cows are 'on' the ground, not inside of it; next time I'll ask her to show me a sign that her story is true."

Discussions also revealed that students not only learned basic earthquake preparedness procedures during the curriculum, but they have started to debate the usefulness and practicality of their actions. For example, a number of students raised concerns about the practicality of a 3-day safety kit in their homes when they spend half of their day in schools: "Even if we have a 3-day kit at home, when there's no kit at school, what are we supposed to do when an earthquake hits and we are in school?" This statement demonstrates that students have started to realize that there is a need for a safety kit at their schools. A few students also mentioned that they discussed the importance of having a safety kit with the school's principal.

Codification Activity Observations and Assessment – Students displayed differing levels of comprehension when integrating curriculum material into their stories. Some students relied very heavily on the scientific information covered in the lessons, writing stories with detailed descriptions of earthquake mechanisms, the associated damages, and character responses that indicated awareness or forethought when faced with an earthquake and its aftermath. Some students, however, demonstrated little comprehension of any connections between the concepts described in the curriculum, as indicated by simply listing disconnected scientific facts and numbers out of context. This demonstrated memorization of the concepts but little or no verification of the ability to apply, further develop, or interpret these ideas under unstructured circumstances. However, as the post-assessment data reveal, it is possible that some of these students may have understood the material, but simply lacked writing skills. Most students included personal stories and cultural anecdotes in their stories. Figure 3-4 shows an example of pages from students' books.

Despite different levels of comprehension, all students described the codification activity as "the most exciting" part of the curriculum because they published a book of their own. Students' requests for making multiple books or stories during this activity indicate their active participation. While it is difficult to effectively assess students' understanding of the curriculum materials in this activity, it certainly instilled a sense of pride and accomplishment in students.

4. Curriculum Evaluation

We assessed the effectiveness of the curriculum lessons by comparison of pre- and post-assessment data. This approach was appropriate since students answered the same questions during pre- and post-assessment activities.

Students' comprehensive understanding of earthquakes and the related physical processes was revealed in the post-assessment activity where they used the knowledge they gained from the science lessons to answer basic questions, generate discussions, and raise fundamental questions. The high level of enthusiasm and engagement with the content during the post-assessment discussions indicated active participation of students. When discussing the causes of earthquakes, students made verbal and non-verbal (hand gestures) references to models they built and operated during the science lessons. For instance, one student gestured pulling on a rubber band as another described accumulation of elastic energy in rocks. Students demonstrated mountain building, subduction, divergent and shear motions along plate boundaries using hand motions when discussing plate movements. Most students discussed the mountain building processes in a regional context, as one student explained, "because of India-Eurasia collision, Earth's crust wrinkles and mountains are formed." Students initiated a debate on the driving mechanisms of plate tectonics, and argued about the velocity of the Indian plate with respect to Eurasia. In their discussions, students only mentioned earthquake legends and myths only to disprove them in a scientific context. "People ask us why earthquakes occur and we say because of plate tectonics, then they ask us why plate tectonics occurs," one student asked, looking for a convincing argument to use when sharing information with others.

Students' interactions and discussions during the post-assessment activity support the effectiveness of the science lessons in this curriculum. As previously discussed, no student understood or used scientific terminology when discussing the causes of earthquakes and the related physical processes in the pre-assessment interviews. The post-assessment discussions show a significant improvement in students' understanding of earthquake science and a better understanding of the scientific process. The science lessons equipped students with knowledge necessary for becoming active participants in hazard reduction processes.

Students' awareness of earthquake hazards is evident in post-assessment discussions during which they pointed out local hazards such as landslides, liquefaction, structural collapse, and non-structural hazards, all covered during hazards lessons. The hazards lessons not only raised students' awareness, but provided an opportunity to introduce and discuss mitigation strategies. Unlike the pre-assessment responses, in post-assessment discussions students described protective actions to take before, during, and after an earthquake. Students listed quick evacuation of the building during an earthquake, but emphasized "drop, cover, and hold" procedure if quick evacuation is not possible. In post-assessment discussions, students demonstrate the importance of planning ahead for earthquakes, a concept unfamiliar to all students during the pre-assessment interviews. "We need to be able to take care of ourselves before the help arrives," one student said. More specifically, students discussed the importance of finding and fixing hazards, developing a family and community emergency plan, and making a 3-day safety kit as recommended by the Federal Emergency Management Agency (FEMA). During the discussions, a number of students claimed to have already taken small actions to reduce hazards (e.g., making a kit, fixing non-structural hazards in their homes, speaking to parents and schools' authorities about earthquake planning). All of these actions demonstrate the effectiveness of the hazards and mitigation lessons in communicating vital and relevant information with students.

The most notable remark indicative of successful implementation of the curriculum is revealed in students' interactions during post-assessment discussions where they chose to brainstorm ideas together to answer questions or to generate solutions to problems. For instance, the discussion on the usefulness of a 3-day safety kit was initiated by students during which they concluded that there is a need for a safety kit at their schools. Students then discussed sharing this information with the appropriate school authorities. This indicates that the curriculum has not only provided a means for effective dissemination of information, but it has empowered and unified them with knowledge necessary to generate discussion, agree upon solutions, and take actions to protect themselves.

5. Concluding Remarks

There is a high probability (about 40 percent) that an earthquake will occur near the capital of a Central Asian republic within the next twenty years, with potential to cause over 55,000 fatalities and over 220,000 serious injuries in Dushanbe alone (Khalturin et al., 1997). Minimization of earthquake disaster impacts in many parts of Central Asia depends not only on the reduction of physical and social vulnerabilities, but also upon individual and community empowerment through the reduction of "informational vulnerability" (Degg and Homan, 2005). Therefore, knowledge sharing between experts and the general public is highly critical. Sharing earthquake information with young Tajiks is, therefore, not simply an exercise; it can save lives and anguish as the possibility of a large earthquake in Dushanbe looms in the near future.

Our stepwise approach to earthquake education with middle school students in Dushanbe has been demonstrated as an effective method for dissemination of scientific information to young people. Our science lessons have enabled students to understand and use appropriate scientific terminology when describing earthquakes and related physical processes. The hazards lessons have increased students' awareness, but most importantly, they have empowered students with knowledge and skills necessary for utilization of all resources for their protection before, during, and after an earthquake. The codification activity has played an important role in linking the curriculum concepts together, and instilling a sense of pride and accomplishment in the students. As a result of the curriculum, some students have started to think critically when sharing and receiving information. One of the most significant and exciting outcomes is that most of the participating students developed an innate interest in Earth sciences, particularly earthquake science and hazards.

Acknowledgments

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Figure Captions:

Figure 3-1. Curriculum stepwise approach

Figure 3-2. A student operates a model for the stick-slip behavior of a fault.

Figure 3-3. Students test their building models on a shake table.

Figure 3-4. An example page from a student's book.

Table 3-1. Curriculum components, learning objectives, and related activities.

Week	Components/Lessons	Objective	Activity
1	**Pre-assessment**	To assess students' perceptions and perceptions about earthquake hazards and Earth sciences prior to the lessons; to establish interpersonal relationships between students and the educator; and to allow for communication of curriculum's key elements.	The pre-assessment activity consists of one-on-one reciprocal interviews between the students and the educator; students are encouraged to ask and answer simple questions and to share concerns they might have prior to the lessons.
2	**Earth interior & plate tectonics**	To develop an understanding of the interior structure of the Earth, and relationships to plate tectonics and occurrences of earthquakes	Students compare the interior of a hard-boiled egg to that of the Earth, and explore limitations associated with this analogy.
	Plate boundaries	To explore what happens at plate boundaries; to learn how the scientific process works.	Students observe, describe, and classify scientific data to learn about what happens at plate boundaries.
	Properties of Earth materials	To demonstrate why and how rocks deform.	Students investigate how materials' properties can change using rubber bands, silly putty, metal wires and tootsie rolls.
	Plate motions and faulting	To learn about different kinds of faults produced by different kinds of plate motions.	Students compare Earth's crust to modeling clay and observe it when under stress. Students use strips of cardboard to construct fault models.
	Earthquake Machine	To incorporate information from previous four lessons to understand mechanisms behind earthquakes.	Students build and operate a model to observe stick-slip motion along a fault, and explore the effects of several variables.
	Seismic energy	To learn how earthquake energy is released, transmitted through the Earth, and measured.	Students use Slinky toys, telephone cords and ropes to learn about different waves and their motions.
3	**Liquefaction**	To learn the effects of liquefaction and what can be done to reduce damage due to liquefaction.	Students construct a model using sand of various particle sizes to investigate the degree of liquefaction and its effects on structures.
	Landslides	To learn how and why landslides occur, and steps to take to reduce landslide hazards.	Students construct a model to simulate an earthquake-induced landslide and explore factors that affect an earthquake-induced landslide.
	Structural hazards	To understand how buildings respond to earthquake forces; why they collapse and what can be done to make structures safer.	Students construct building models and test them on a shake table; they build a wall model and reinforce it to withstand shaking.
	Non-structural hazards	To assess safety of the classroom (and homes) and to make a plan to remedy earthquake hazards.	Students identify non-structural hazards in their schools (and homes) by developing and completing a rapid visual screening (RVS) checklist.
	Earthquake Emergency Response Plan and Drill	To recognize the early signs of an earthquake; to develop an awareness of proper safety measures to follow before, during, and after an earthquake	Students develop, test, evaluate, and improve an emergency response plan and a drill for their school. Students present their plans to appropriate school's authorities. Students develop an emergency family plan and put together a 3-day safety kit.
4	**Codification Activity: Bookmaking**	To help students reinforce the concepts learned from all aforementioned lessons.	Students use information from curriculum lessons to write a story about individuals or communities affected by an earthquake. Students illustrate, publish, and present their stories in their school.
5	**Post-assessment**	To measure students' performance and the effectiveness of instructional methods.	Students participate in a group discussion about the material covered in the curriculum and provide feedback to the educator.

Table 3-2. Students' responses to past and future earthquakes

	Immediate response to EQ in the past (%)	**Immediate response to EQ in the future (%)**
No action	37	25
Escape or Run away	56	50
Shelter	7	25

Table 3-3. Students' explanations of causes of earthquakes

Response Category	**Total responses (%)**
Scientific explanation	0
Disconnected scientific concepts or terminology:	
● extraction of natural resources	12
● volcanoes, lava, mountains	39
● avalanches, flood, waves	7
Non-scientific	
● legends	9
● religion	5
No explanation	28

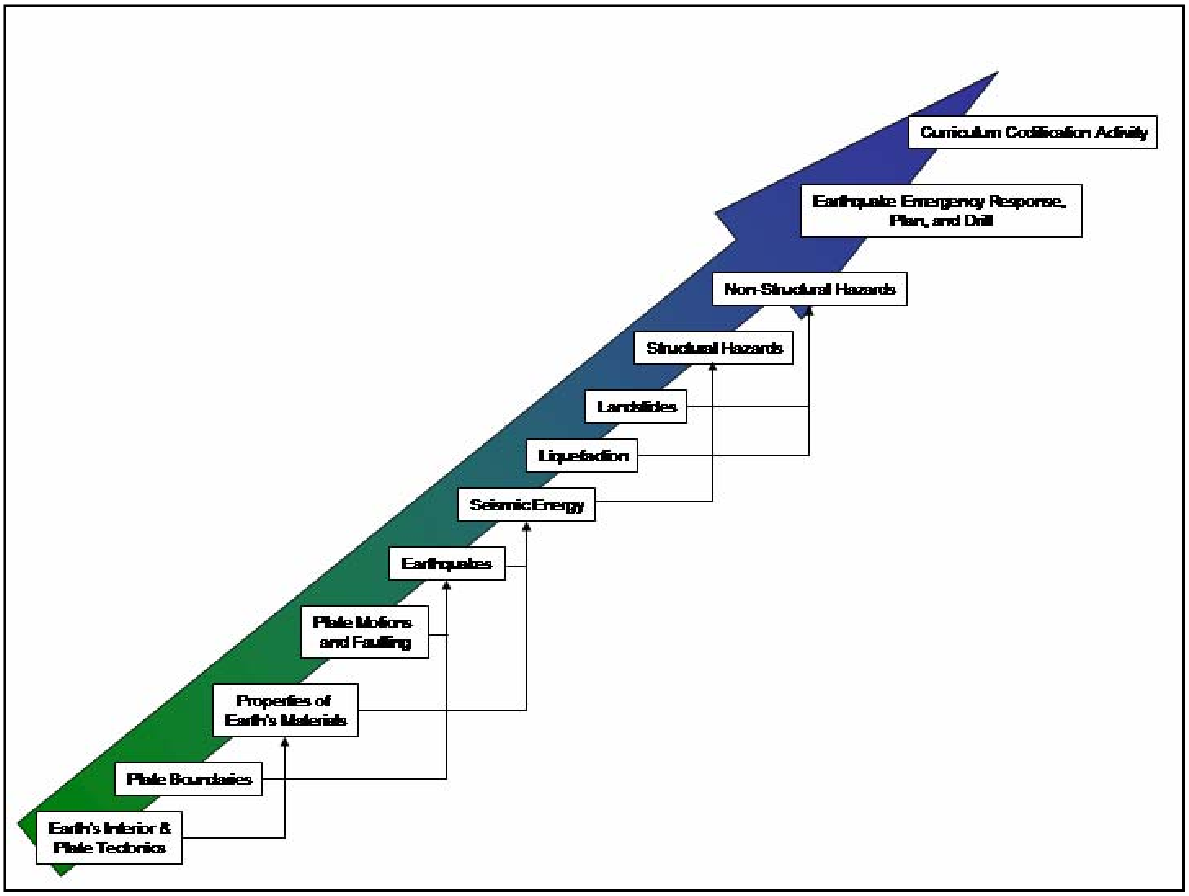


Figure 3-1.

Figure 3-2.

Figure 3-3.

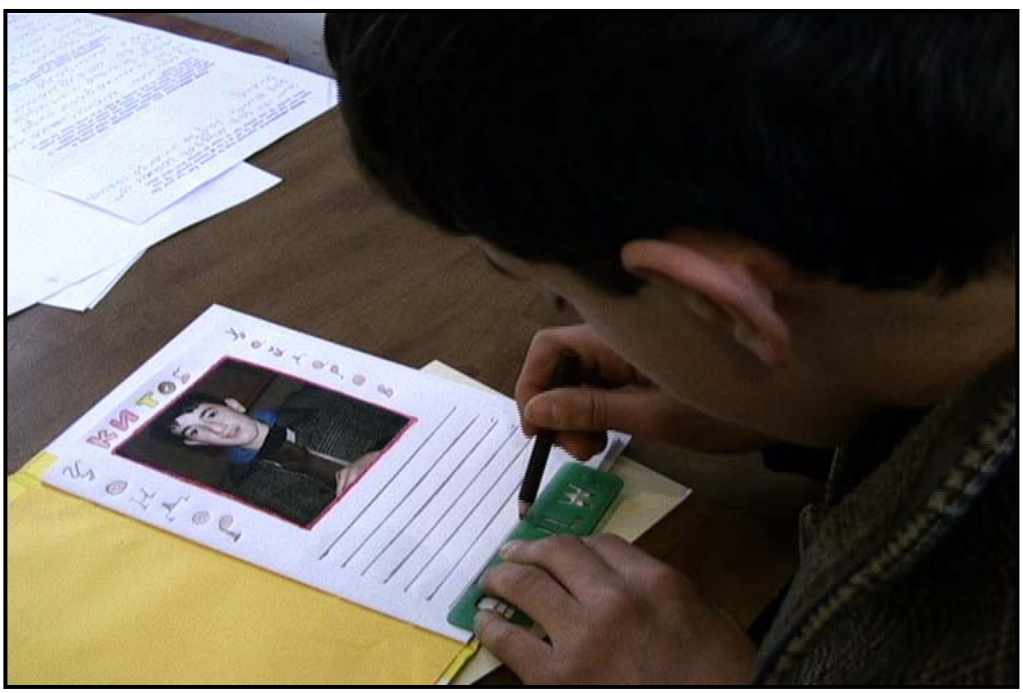


Figure 3-4.

To learn why, where, and how earthquakes happen, you need to familiarize your students with the interior of the Earth and a model called plate tectonics. Plate tectonics is the engine behind the earthquake machine. The first step towards learning about plate tectonics is to learn about the Earth's interior structure. This lesson should address both of these topics.

This activity is designed for one 1-hour class period.

This lesson is modified from an activity created by Molnar (2002).

Materials

Copies of Handout No. 1 (one per student)
Hard-boiled egg (one per student)
Plastic knives, plates, and napkins (one per student)

Introduction

1. First, ask students what a globe represents. Explain to them that a globe is a model of the Earth. Scientists use models to represent objects.

2. Present a model of the Earth's interior (Handout No. 1). Ask students how they think scientists know what the Earth is made of. You may want to start with a simple example your students can relate to (guessing what is inside of a wrapped present by shaking, weighting, feeling, smelling, etc.). Explain that scientists study seismic waves generated by earthquakes, vibrating machines, or explosions to learn about the interior of the Earth. Seismic waves bend and reflect at the interfaces between different materials (see Lesson 6). Use an example your students can relate to (checking the ripeness of a watermelon by tapping on it). Tell students there are other ways that scientists study the interior of the Earth: drilling holes, studying material brought up to the surface by volcanic eruptions.

3. Explain that the Earth is made of three main layers: crust, mantle, and core. Draw them on the board using colored chalk. Explain that the core is divided into two layers: solid inner core, and liquid outer core. Ask students how scientists know about the liquid and solid nature of the two layers. Explain seismic waves travel at different velocities when they pass through different states of matter.

4. Tell your students that the crust is broken into pieces. Scientists refer to these pieces as plates. The plates move relative to each other. This is called plate tectonics. Tell them they will learn about the three different kinds of plate motion in this lesson.

5. Tell your students that now they are going to use an egg as a model of the Earth's interior.

Procedures

1. Provide each student with a hard-boiled egg, a plate, a plastic knife, and a napkin.

2. Ask students what part of the Earth the eggshell represents.

3. Ask students to gently tap the egg on the table to produce cracks all around the egg. Ask them what the shell pieces are referred to on the Earth.

4. Ask students what layer of the Earth is shown through the shell.

5. Now ask the students to squeeze their eggs gently until slight movement of the shell pieces occur. Ask students to look for places where pieces of the eggshell separate, come together, or pass one another. Ask them what they see (the shell buckles in some places, in other places it exposes the white part of the egg). This is how Earth's tectonic plates move. This results in formations of mountains, new ocean floor, and earthquakes. Introduce the term plate boundary. It is where the earth's plates approach each other (buckling of eggshells), move away from each other (exposing the white part of the egg), and pass one another.

6. Show students how to cut their eggs.

7. Ask students to name the different layers of the Earth's interior using the egg as a model that represents the Earth.

Caution! The egg analogy has some limitations. Eggshell pieces, for the most part, have the same density whereas the plates on earth vary in density. Oceanic plates are denser than the continental plates, for example. The eggshells do not move whereas the plates move. The egg has one inner section (yolk) whereas the earth's core is comprised of a solid inner core and a liquid outer core. It is worthy to mention these limitations to your students.

8. Eat the egg.

Useful Internet Resources

Surface and Interior of the Earth:
http://www.windows.ucar.edu/tour/link=/earth/Interior_Structure/overview.html&edu=elem

References

Molnar, L., 2002, Earth's interior and plate tectonics theory, available online at: http://www.eduref.org/Virtual/Lessons/Science/Earth_Science/EAR0203.html

Lesson 2: Discovering Plate Boundaries Supplementary information: 3-2

Plate boundaries are where the action is. A large fraction of all earthquakes, volcanic eruptions, and mountain building occurs at plate boundaries. It is also where most of the people on Earth live. In this lesson, students use scientific data to learn how the scientific process works. They learn where the Earth's tectonic plates and their boundaries are, what happens at the boundaries, and how scientists classify plate boundaries. This curriculum encourages students to observe, describe, and classify scientific data to learn about a scientific process.

This activity is designed for three one-hour class periods over several days, but it can be done in a three-hour lab period.

This lesson is modified from curriculum developed by Sawyer et al. (2005).

Materials

Copies of plate boundary map (2 per student)
1 copy of seismology map
1 copy of volcanology map
1 copy of topography/bathymetry map
1 copy of geochronology map
1 copy of Graphic No. 2 (attached at the end of lesson)
Colored pencils

Note! All the above maps can be downloaded directly from:
http://www.geophysics.rice.edu/plateboundary/downloads.html

Introduction

1. Explain to students that the most important key to scientific progress is the ability to observe, describe, and classify information or data. Give them an example they can relate to (visiting a doctor when sick: a doctor observes, describes and classifies when making a diagnosis).

2. Tell them they are going to learn about the plate boundary processes. Based on Lesson 1, they should be able to tell you what plate boundaries are. Tell them they are going to discover on their own what takes place at the boundaries. They are going to observe, describe, and finally classify the data provided.

3. Tell students this allows them to learn about plate boundaries as a doctor learns about the human body.

4. Depending on your students' current level of Earth sciences knowledge, you might want to explain to them what the following terms mean: seismology, volcanology, geography, and particularly geochronology. They will be using these terms throughout this exercise.

Procedures

1. Hand each student a plate boundary map and a slip of paper with a Scientific Specialty (Seismology, Geochronology, Volcanology or Geography), and a plate name (Pacific Plate, North American Plate, India Plate, etc.). The goal is to have each student have a different combination of specialty and plate, and for all scientific specialties to be covered for each plate used in the exercise.

2. Then ask students to assemble in their specialty group at their respective maps: Seismologists at the earthquake map, volcanologists at the volcano map, Geochronologists at the sea floor age map, and geographers at the topography map.

3. Ask each group to become familiar with their map, and read the side label to see what is being displayed and how it is being displayed. They should work as a group to figure out what they are looking at. Circulate among the groups listening and clarifying misconceptions. This should take about 10-15 minutes. Remind students that they are to observe rather than describe or interpret.

4. Ask each group to start describing what they see. Their descriptions should include words like deep or shallow, active or inactive, ridge or valley, symmetric or asymmetric. Each group is to work only with its data map. Students should only be talking rather than writing.

5. Now ask them to classify their data. Each group is to come up with a classification of the plate boundaries of the world based on their data. They are to use up to five plate boundary type classifications. These are to be given numbers like boundary type 1, boundary type 2, etc. They are not to use plate tectonic terminology. Ask them to write a description of how they identified their plate boundary types.

6. Ask them to use color pencils to mark (on their individual plate boundary map) all plate boundaries in the world which fit that description. They should use different colored pencils for each of their boundary types. They will each be asked to turn in the marked maps at the end of the exercise (Day 3)

Caution! At first this might seem confusing. Get your students on track by asking someone in the group select a plate boundary segment. Ask them to tell you what their data show on or near that plate boundary segment. For instance, the seismologist might notice that there are only shallow earthquakes along that boundary and/or that the line of earthquakes and the plate boundary both have a zigzag pattern. Then suggest to them that they have just defined their type 1 boundary. Ask them to mark the boundary type identifications in colored pencil on the map. Ask them to find other plate boundary segments that fit this description. They should repeat this process by finding a plate boundary segment that they have not yet marked and repeat the whole process to define a type 2 plate boundary.

7. Move from group to group assisting and questioning where it seems appropriate. Ask students to keep their maps and plate boundary type classifications to be used later in the exercise. This is the end of Day 1.

8. On Day 2, assemble students in their plate groups. Each plate group should consist of a seismologist, a volcanologist, a chronologist, and a geographer. This will be a different group than they worked with on Day 1.

9. Tell them that each group contains experts on all the data types, but that each expert has only looked at data in their own specialty. Each group needs to work their way around the maps to become familiar with all the data. At each map, the expert on that map should make a brief presentation to the others in their group about their data. Each student is an expert and each gets to present their data when they arrive at their maps. Each presenter should first tell others what the data are and how they are symbolized, pointing at the most important features on their map. They should introduce the plate boundary types from Day 1 and where they can be found in the world. All presentations put together should not take more than 15 minutes.

10. The next step is to ask students to come up with a new classification scheme for the boundaries of their plate (not the whole world). This scheme should be called boundary type A, boundary type B, etc. Most importantly, the scheme should now be based on all four data types. For example, boundary type A might be described as having shallow earthquakes on the plate boundary, sparse or no volcanoes, lying on a topographic high, and following a line of young sea floor. Each student will have to make and turn in this new map, showing their boundary type descriptions on the back and colored boundaries on the map, at the end of the exercise (Day 3).

11. Towards the end of Day 2, tell the students that a spokesperson from each group will need to speak to the class at the beginning of Day 3. This is the end of Day 2.

12. On Day 3, students make their presentations. Ask them to describe their plate boundary classifications, and then to give a tour around their plate.

13. Spend the remainder of the class time discussing plate boundaries processes and introducing the terminology Earth scientists use to describe these plate boundaries. Use Graphic No. 2 to discuss convergent, divergent, and transform boundaries. Explain why each of these boundaries have the particular observable phenomena the students have seen.

14. Have the students turn in their two annotated plate boundary maps.

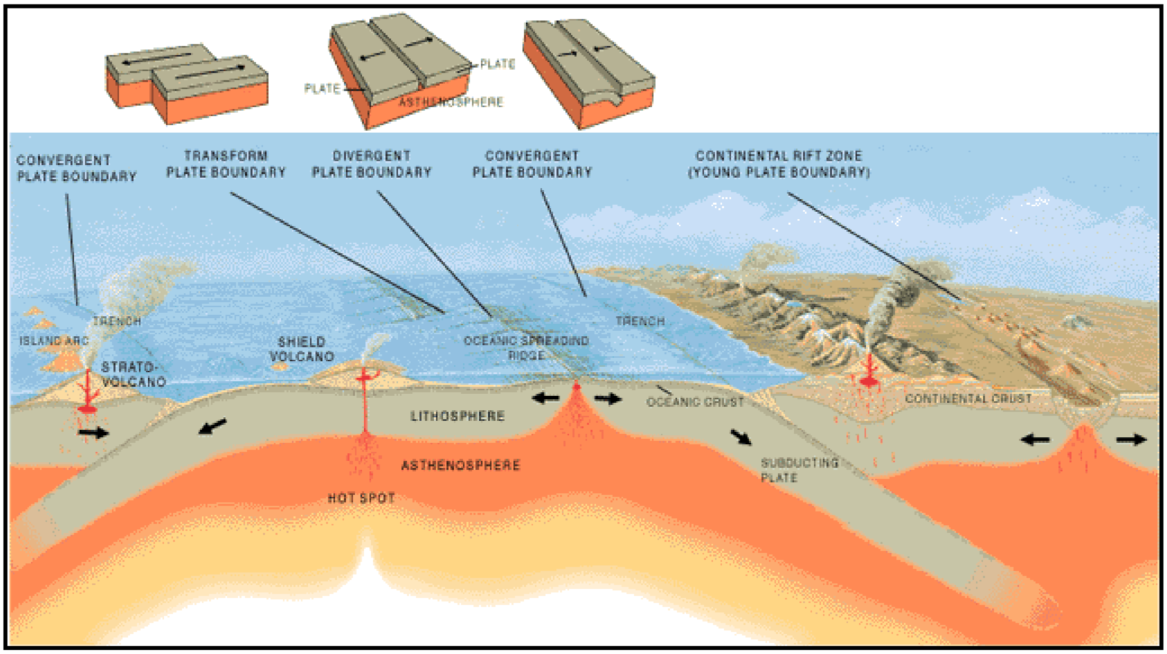
Useful Internet Resources

Teacher's Guide on this activity:
http://terra.rice.edu/plateboundary/tg.html

References

Sawyer, D.S., Henning, A.T., Shipp, S., Dunbar, R.W., 2005, A data rich exercise for discovering plate boundary processes, Journal of Geoscience Education, v. 53, n. 1, p. 65-74

Graphic No. 2



Rocks are forced to change shape at or near plate boundaries. Rocks can experience squeezing, stretching, or pushing in different directions in response to stress. This response depends on the type of stress, the rate at which it is applied, the environmental conditions of the rocks, such as temperature and pressure, and their composition. This lesson addresses the following questions: How do rocks deform, what factors play an important role in defining the behavior of rocks, what happens when rocks deform, and finally, why do rocks deform? Understanding the answers to these questions helps us better understand the physical processes that cause earthquakes.

This activity is designed for two one-hour class periods over two days, but it can also be done in one two-hour lab period.

Materials

Small metal springs
Rubber bands (cut in the middle to produce an elastic string)
Silly putty (enough to be shared evenly amongst the students in the time allowed)
Unbent paper clips or pieces of metal wire
Tootsie rolls (two pieces per student, refrigerated overnight)
Photo No. 3a: ductile deformation of rocks
Photo No. 3b: brittle deformation of rocks

Introduction

1. Tell students that energy is the ability to move things around, or to cause any kind of change in the environment. Have them name some examples of how energy causes changes around them. Examples include chemical energy in fuel produces heat, which can be used to produce movement like in cars or trucks; or how movement energy can be turned back into heat through friction by rubbing hands together. Earthquakes move things around and cause changes in the environment, therefore earthquakes are about the movement of energy. The reason earthquakes occur is because energy is absorbed, stored, and released in Earth's materials.

2. Tell students that they are going to learn about some of the basic structural properties of materials. They are called 'structural properties' because, for the purposes of this exercise, we are interested only in the ability of materials to hold shapes or move energy as if they were part of structures. Have students name some examples of simple and complex structures (such as tables, chairs, bridges, buildings, etc.). Tell them that our everyday experiences with different materials are very helpful for hypothesizing about how materials will react when energy is applied to them in different ways. That is the basis for doing this exercise.

3. Explain to the students the meaning of the following words. Have students provide examples of materials that fit each description:

Elastic: material that returns to its original shape after being deformed (i.e., rubber)
Inelastic: material that does not return to its original shape after being deformed. There are two main sub-categories of inelastic materials: brittle (material that cracks or fractures easily without much stretching such as glass), and ductile (material that can be drawn, stretched, or compressed into a deformed shape without breaking such as silly putty at room temperature).

4. Briefly explain what stress means: stress refers to the amount of force applied per unit area of material. Give them a simple example: when a person smashes an aluminum can using one foot, stress is being applied to the can. Explain what strain means: it refers to the change in shape of a material. A crushed can is strained in the above example. Therefore, stress causes strain.

Procedures

1. Organize four areas within the classroom. At each area, put out a rubber band, metal wires, silly putty, and small metal springs.

2. Divide the students into four groups and have them spend a few minutes at each area. Ask them answer the following questions for each material:

Is the material elastic or inelastic?
If the object is inelastic, is the material brittle or ductile?
What other materials are similar to this material?
Does this object's material behave like the rocks that make up Earth's materials? Why or why not?

3. After everyone has had some time with each material, go over the students' responses and classify each material. The answers should be something like this:

Rubber band: elastic
Metal wires: inelastic, ductile
Silly putty: inelastic, ductile (some may say brittle; see step 9)
Metal springs: elastic (some may say ductile, if the spring is stretched too far; see step 10)

4. Explain to students that rocks can deform brittlely and ductilely just like the material they just experimented with. Show your students Photo No. 3a and 3b. These two photos show two deformed rock outcrops on the Earth's surface. Ask them explain what kind of deformation they observe in each photo. Ask them if they have seen any other similar rock outcrops.

Caution! Keep in mind that geologic structures may show evidence of more than one type of deformation.

5. Now tell students they are going to investigate how materials' properties can change according to environmental conditions. Distribute two cold tootsie roll candies to each

student. Have the students speculate about what the properties of the candy are (i.e., elastic or inelastic, ductile or brittle). The cold tootsie roll should be inelastic and brittle. This can be demonstrated by hitting the candy sharply on the table- it should fracture into smaller pieces within the candy wrapper. Have the students try to deform the candy in different ways (stretching, compressing, bending), and explain that these are all examples of trying to get the candy to absorb energy.

6. Now, have the students warm the second piece of candy (i.e., by holding it between their hands, or sitting on it, or putting it in their mouth). After the candies are made quite warm, have the students try to deform the candy in the same manner as was tried with the first candy. The candy should now be much more flexible, compressible, and stretchable than before. Some of the candies may still break but the behavior will be quite different. The candy can be permanently deformed into a new shape without breaking with the addition of heat. You may ask the students name other processes where this property is useful. Examples include metalworking, where iron, steel, or aluminum is heated so that it can be made into new shapes.

7. Describe that the same behavior happens for many types of rocks. Tell the students that temperature and pressure increase as one goes deeper in the Earth, and so that the deeper Earth material (mantle rocks) are more easily described as an inelastic, ductile material than as elastic, brittle materials that crustal rocks seem to be. Below the Earth's surface, pressure prevents rocks from separating into fragments. In determining the transition from brittle to ductile behavior, temperature and pressure as well as deformation rate, and material composition are important.

Caution! Crustal rocks may exhibit ductile behavior under stress. Folding is one example. *Pressure solution creep* is a mechanism that can account for the ductility of crustal rocks at low temperatures and pressures. This process involves the dissolution of minerals in regions of high pressure and their precipitation in regions of low pressure. This results in creeping of rock.

In addition, ductilely deformed rocks deeper in the Earth can be brought up to the Earth's surface by regional uplift and erosion.

8. Distribute the silly putty among students. Ask them to roll the silly putty into a small cylinder about 5-10 centimeters long. Grabbing the cylinder with both hands (each at one end), ask them to quickly yank the silly putty in half so that it fractures cleanly in the middle. Now ask them to roll the silly putty back to its cylindrical shape, and with both hands (each at one end) pull it apart very slowly. Ask them what happens (slow change in shape, it stretches and doesn't break). Ask the students if silly putty is elastic, inelastic, or both, and why. Encourage them to describe the conditions that lead to the behaviors they observed. Explain to the students that while the words we use (elastic, inelastic, etc.) describe behaviors of the materials, that all materials actually exhibit a mix of all properties depending on the conditions they experience.

9. To summarize the silly putty experiment, tell students the rate at which a material deforms dictates the behavior of the material. A sudden change in shape of rocks can cause brittle deformation (it can break the rocks), whereas a slow change in shape can cause ductile deformation (causing foliations in rocks).

10. Next, distribute the springs that were used in the first part of the exercise. Review that the spring appears to be an elastic material since it can be deformed and return to its original shape. Take the spring and stretch it to the point where it does not return to its original shape. It should be slightly longer than before, but still retain its elastic properties. Recall that scientists say the object has been strained. Ask the students if this material elastic, inelastic, or both? Why or why not? Under what conditions? Explain to the students that while the words we use (elastic, inelastic, etc.) describe behaviors of the materials, that all materials actually exhibit a mix of all properties depending on the conditions they experience.

11. Summarize all the above factors (temperature, pressure, deformation rate, and composition) that dictate the behavior of Earth's material.

12. Now distribute the rubber bands. Ask students to stretch the rubber bands. Ask them to predict what would happen if they let go of them (the rubber bands can fly a good distance and potentially harm someone). Ask them explain why the stretched rubber band may pose potential hazard (the potential energy stored in the stretched rubber band is released in the form of kinetic energy when it is released). Describe to the students that Earth's crust can act like an elastic material and is capable of absorbing energy just like a rubber band. This stored energy can be released later (quickly or slowly) as earthquakes.

13. Finish the discussion by encouraging students to learn more about the causes of deformation and their relation to earthquakes in more depth in Lesson 4.


Photo No. 3a – Northern Tajikistan


Photo No. 3b – Northern Pakistan

Lesson 4: Plate Motions & Faults Supplementary information: 3-4

As observed in Lesson 3, at low pressures and temperatures rock is a brittle material that will fail by fracture if the stresses become sufficiently large. When a lateral displacement takes place on a fracture, the break is referred to as a fault. Earthquakes are associated with displacements on faults. In this lesson, students learn about the different kinds of faults produced by different kinds of plate motions discussed in Lesson 2, and their relation to earthquakes.

This activity is designed for one 1-hour class period.

This activity is modified from a lesson created by Todd et al. (2004).

Materials

A soft ball of dough
Small amounts of flour
Strips of cardboards (1 per group)
Colored pencils
Scissors
A copy of Handout No. 4 (1 per student-attached at the end of lesson)

Introduction

1. Remind students of lessons learned from Lesson 3. Have a student define Stress and Strain.

2. Explain that there are three kinds of stress: compression, tension, and shear. Give them an example they can relate to. Ask students to predict what happens to a ball of pizza dough when they squeeze it between both hands. Then hand a student a soft ball of dough and ask the student to show what happens (you might want to dust the student's hands with small amounts of flour prior to touching the dough to avoid stickiness). The dough becomes squeezed into less space. Tell students they have compressed the dough. This stress is call compression. It changes the shape of the dough by shortening it. Ask students to predict what happens if they stretch the dough. Invite a student to demonstrate this. The dough becomes thinner and longer. The stress applied by students is called tension. It changes the shape of the dough by lengthening it. To demonstrate the third kind of stress, ask two students to stand next to each other, holding on to the ball of dough. One student should face the blackboard, while the other should face the rest of the students in the class. Ask students to predict what happens to the dough if both students start to walk. The dough is sheared and may eventually become torn apart into two pieces. This is called shear stress.

3. Ask students what kind of plate motion results in compression in rocks, what kind produces tension in rocks, and what kind shears rocks. Students should use the information acquired in Lesson 2 and from playing with the dough to answer these questions. Explain to students that different kinds of plate motions produce different kinds of stress, and

different kinds of stress produce different kinds of strain (deformation) in rocks. Convergent plate motion results in compression in rocks, Divergent plate motion produces tension in rocks, and transform plate motion shears rocks. This should be easy to understand after experimenting with the dough. The dough is the rock in this experiment.

4. Remind students of what they learned in Lesson 3: The outer part of the Earth is relatively cold, and when it is stressed it tends to break (like breaking a piece of cold silly putty). Explain to your students that these breaks or fractures, across which displacement occurs, are called faults. Tell them there are different kinds of faults (strike-slip, normal, and reverse faults). If you have pictures of faults and fault ruptures, now is a good time to share them with your students. Tell your students they are going to build models of the above faults in this lesson.

Procedures

1. Divide your students into three groups (Group 1, 2, and 3). Hand each group one strip of cardboard, one pair of scissors, and colored pencils.

2. In Group 1, instruct one student to color a road with several houses along it on their piece of the cardboard. This piece represents a bird's eye view of the Earth's surface from above. Then, ask one student to make a vertical line from a point at the center of the cardboard. The line should split the cardboard in two, and should cut across the colored road. Instruct a student to cut along this line. See Figure 1.

In Group 2, instruct one student to color horizontal layers of rocks on their piece of cardboard (you might want to show your students a picture of a mountainside with layers in it). This piece of cardboard represents a cross-section of the Earth (analogous to cutting a cake and observing the internal layers). Students should mark a point at the center of the cardboard, and draw a line at a 45^o angle to the rock layers, from the center point to the outside edge of the cardboard, splitting the cardboard in two. Ask them to cut along this line. See Figure 2.

Give students in Group 3 the same instruction as the ones given to Group 2. Also, see Figure 2.

3. Meet individually with each group. Explain to the students in Group 1 that they have produced a model of a strike-slip fault where one block of rock slides past another horizontally (Figure 3). Ask them to show you this motion using their cardboards. Ask them what happens to the road cut by the fault. Ask them what kind of stress results in this type of fault (compression, tension, or shear). Ask them near what plate boundary (convergent, divergent, and transform) one can expect to see this kind of fault. Explain to them that earth scientists distinguish between two types of strike-slip faults, based on the relative movement of one side of the fault with respect to the other. If they stand facing the fault, they can say it is a left-lateral strike-slip fault if the block on the far side slipped to their left, and that is a right-lateral fault if the block on the far side slipped to their right.

Explain to students in Group 2 that they have created a model of a normal fault. The fault is marked by the cut in the cardboard. In a normal fault, the rock above the fault plane moves down the slope of the fault (Figure 4). Ask a student to demonstrate this using the cardboard. Remind them that the cardboards represent a cross-section of the Earth. It might help if they hold the cardboards perpendicular to the surface of their table, and imagine looking at a mountainside across a road that cuts through it. Ask them what kind of stress results in this type of fault. Ask them near what plate boundary one can expect to see this kind of fault.

Explain to students in Group 3 that they have produced a model of a reverse fault. The fault is marked by the cut in the cardboard. In a reverse fault, the rock above the fault moves up the slope of the fault (Figure 5). Then ask them the same questions as the ones used in Group 1 and 2. Mention to the students that thrust faults are reverse faults that develop at a very shallow angle.

4. Invite one student from each group to give a brief report to the class on the fault motion discussed in their groups. Each student presenter must demonstrate the sense of motion on their faults using their cardboards, name the stress that creates them, and name the plate motion that may contribute to their formation.

5. Allow students to exchange their fault models. It is encouraged to allow each student try all of the models. Hand each student a copy of Handout No. 4. Ask them to complete and turn in the handout by the end of lesson.

6. Explain to the students that earthquakes occur on faults. Strike-slip earthquakes occur on strike-slip faults, normal earthquakes occur on normal faults, and thrust earthquakes occur on thrust or reverse faults. When an earthquake occurs on one of these faults, the rock on one side of the fault slips with respect to the other, just as what they observed when experimenting with their fault models.

7. Finish the lesson by asking students if the motion along faults occurs smoothly. Encourage them to use their cardboard models to explore this question. Students should be able to observe that sometimes their two pieces of cardboard lock together, and that they have to apply more force to unlock them. Explain to them that faults also lock, and a displacement occurs when the stress across the fault builds up to a sufficient level to cause rupture of the fault.

8. Ask students to turn in their handouts.

References

Todd, J., Straten, M., Zarske, M.S., Yowell, J., 2004, Faulty movement, available online at: http://nsdl.org/resource/2200/20070917003749908T
Bush, R.M., (editor), 2006, Laboratory manual in physical geology (seventh edition), Pearson Education, New Jersey, 302 p.

Figure 1: Bird's eye view of the Earth's surface

Figure 2: A cross-section of the Earth

Figure 3: Cardboard representation of a strike- slip fault

Figure 4: Cardboard representation of a normal fault

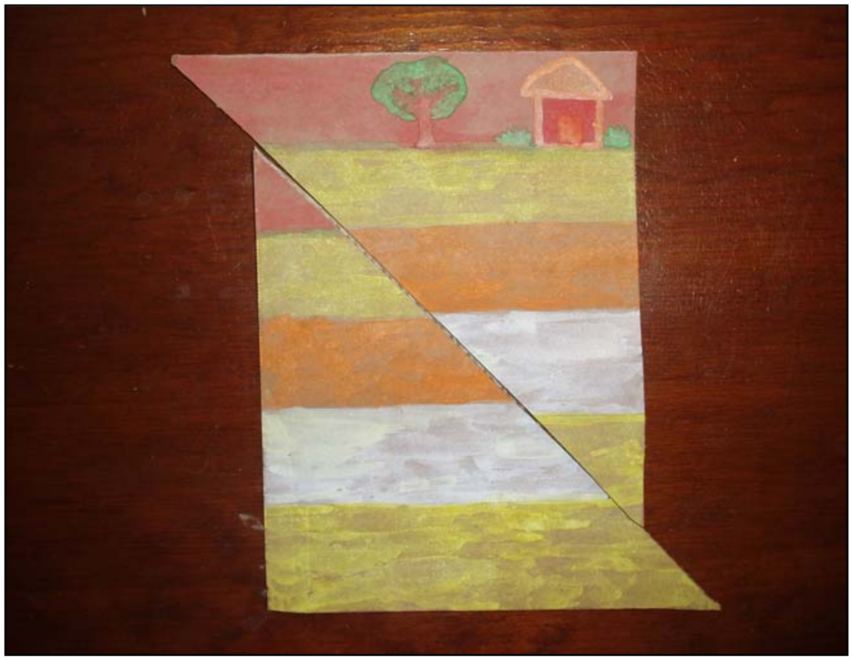


Figure 5: Cardboard representation of a reverse fault

Handout No. 4 Name: _____________

This is a chart for comparing fault types to stress and strain and plate boundary types. This chart was adapted from Bush et al. (2006).

Cardboard Representation	Has the crust **Shortened? Lengthened? Neither?**	Was the stress: **Shear? Compression? Tension?**	Fault Type	Is the plate boundary type: **Divergent? Convergent? Transform?**
			**Strike-Slip fault**	
			**Normal fault**	
			**Reverse fault**	

ANSWER KEY

Handout No. 4 Name: _____________

This is a chart for comparing fault types to stress and strain and plate boundary types. This chart was adapted from Bush et al. (2006).

Cardboard Representation	Has the crust **Shortened? Lengthened? Neither?**	Was the stress: **Shear? Compression? Tension?**	Fault Type	Is the plate boundary type: **Divergent? Convergent? Transform?**
	Neither	Shear	**Strike-Slip fault**	Transform
	Lengthened	Tension	**Normal fault**	Divergent
	Shortened	Compression	**Reverse fault**	Convergent

Lesson 5: Earthquake Machine

Supplementary information: 3-5

As concluded in Lesson 4, earthquakes are associated with displacements on faults. Faults lock and a displacement occurs when the stress across the fault builds up to a sufficient level to cause rupture of the fault. This is known as stick-slip motion or behavior. In this lesson, students observe and understand how stick-slip motion occurs along faults by building a simple model of a fault system.

Caution! Stick-slip motion should not be confused with strike-slip motions along lateral faults.

This activity is designed for two 1-hour class periods or one 2-hour lab period.
This lesson is adapted from a lesson published by Hubenthal et al. (2008).

Materials

Two 4” x 4” wooden block
Two screw eyes, 12x1-3/16”
One 4”x36” sanding belt (50 Grit)
One 1/3 Sheet of sandpaper (60 Grit)
One rubber band
16” of duct tape
One fabric tape measurement
One pair of scissors
One hot glue gun

Note! The above materials are enough for building one model. It is encouraged to divide your students into groups of five, and provide each group with the above materials, so that they can build their own models. To reduce the cost of the materials, you may choose to build only one model for your students and have each student try the model.

Prior to the class, screw one 12x1-3/16” screw eye into the center of one cut end on each wooden block (see Figure 1). Use needle nose pliers to bend the eye of the screw eyes and open them just enough to allow a rubber band and a measuring table to fit through (Figure 2).

Introduction

1. Ask a student to summarize lessons learned from Lesson 4. Make sure students understand the relationship between faults and earthquakes (i.e. when a fault ruptures, the stored energy in surrounding rocks is released, and an earthquake occurs).

2. Remind students that movement along a fault is irregular and not smooth. This is because the surface of the fault plane is irregular, similar to sandpaper.

3. Introduce the topic of friction. Ask students simple questions such as what makes a car stop moving, or what makes an ice skater slow down or stop. Tell students that such examples involve forces that may slow down, stop or make it hard for an object to move. These forces are called frictional forces. Ask your students to think of other examples or ideas that involve friction such as rubbing their hands together on a cold winter morning, lighting a match, or wearing hiking boots when climbing or hiking down steep mountain slopes.

4. Explain to students that the amount of friction depends on two things: the type of surfaces that are touching (smooth kitchen floor versus a dirt road) and the forces pressing the surfaces together (pulling an empty cart versus one filled with groceries).

5. Tell students that faults lock because of their irregular surfaces. It is the force of friction that keeps these surfaces locked.

6. Explain to students that they are going to build a simple model that allows them to visualize what happens along a fault system.

Caution! Remind your students that models are simplifications of complex systems. In Lesson 1 students used an egg as a model of the Earth's interior. Ask students to briefly state a few of the limitations of the egg model. Explain to students that every model has its own limitations. Encourage them to think about some of the limitations of the model they are about to build throughout this lesson.

Procedures

1. Divide students into groups of five. Provide each group with two 4" x 4" wooden blocks (with screw eye already screwed in) , a fabric measuring tape, a rubber band, one 4"x36" sanding belt (50 Grit), one 1/3 sheet of sandpaper (60 Grit), duct tape, glue, and a pair of scissors.

2. Give students the following directions:
a. Cut the sanding belt so that it is no longer a connected loop.
b. Secure both ends of the sanding belt to a classroom table. Make sure there are no waves in the sanding belt.
c. Trace one of the blocks on the back of the sandpaper and use the scissors to cut out a square. Then glue the sandpaper square to the bottom of the block.
d. Place the block on the sanding belt. The block should be on the left end of the sanding belt with the sandpaper glued side touching the sanding belt. The screw eye must be positioned in the center of the sanding belt. Hook the rubber band into the screw eye.
e. Attach the end of the measuring tape to the rubber band.
f. Place the other block on edge and on the right end of the sanding belt. The screw eye should be positioned at the center of the sanding belt.
g. The free end of the measuring tape should go through the screw eye of the block in step f.

Figure 2 shows a complete model. It might be helpful to draw a picture of the model on the board as you give the above directions.

3. Ask one student from each group to stand at the right end of their sanding belt and hold on to the free end of the measuring tape. Ask the student to pull the measuring tape through the eyelet using a slow, steady pulling motion (Figure 3). Invite other students in each group to observe the model carefully as one student pulls the tape. Ask them to list their observations. What happens to the rubber band as the measuring tape is gently pulled? What happens to the block? The rubber band is stretched before the block starts to move. When the block starts to move, the rubber band is no longer stretched.

4. Tell students that they have built a simple model allowing them to visualize what happens at a fault system. Ask them to compare their model with a fault system. What does the wooden block represent? What does the rubber band represent? What about the student who is pulling on the measuring tape? What about the pieces of sandpaper? The model's wooden block and sandpaper base represent an active fault section. Fault planes have irregular surfaces which are represented in this model by the sandpaper. The student who pulls on the measuring tape represents plate motions. The rubber band represents the elastic properties of the surrounding crustal material which are capable of storing elastic energy.

5. Ask one student from each group to demonstrate what happens at a fault system again. As the student is demonstrating this, ask the rest of the students in each group to imagine looking at a fault system, and describe what happens in the system. Then explain to them that because of plate motions at a distance (the student pulling on the tape), elastic energy starts to accumulate in the rocks around the fault (the rubber band is stretched), the fault begins to slip (the blocks begin to move) when the stress across it builds up to a sufficient level. Ask students what the movement of the model's wooden block represents in a fault system. The answer is: an earthquake.

6. Ask them where in their model they can observe friction. Ask a student to recall what friction is. Friction is the force resisting the relative motion of two surfaces in contact. By now, students should be able to point out that friction occurs at the contact surface between the sanding belt and the side of the block covered with sandpaper. Ask students if they are able to pull on the measuring tape without moving the block. Encourage them to try this if they haven't already. Then ask them why they are able to do it. The answer is that the sandpaper pieces are locked together, and this prevents the block from moving. In other words, it is the friction between the two uneven surfaces that prevents the block from moving forward. Explain to the students that in an active fault system, faults also lock. This allows the stress to build up in the surrounding rocks. Once the stress overcomes the forces of friction, the fault slips, and an earthquake occurs. When an earthquake occurs, the stored energy is released by frictional heating on the fault, the crushing of rocks, and propagation of earthquake waves.

7. Ask student to look at the rubber band more carefully after the block moves. Does the rubber band go totally slack after each movement? Allow them to try this a few times. The answer is no. Ask them what this tells them about the release of stored energy on a fault

when an earthquake occurs. Explain that some stored energy remains in the surrounding rocks after an earthquake resulting in aftershocks. Aftershocks are earthquakes that follow the largest shock of an earthquake sequence. They are usually smaller than the main shock.

8. Explain to the students their models demonstrate a process known as elastic rebound theory. Elastic rebound theory states that as tectonic plates move relative to each other, elastic energy (or strain) builds up in the rocks along fault planes. Since fault planes are irregular and not very smooth, they lock and energy starts to accumulate. When the elastic energy overcomes the friction forces that keep the fault planes together, rupture occurs. See Figure 4 for a demonstration of this theory.

9. Now is a good time to discuss some of the limitations of the model. Encourage students to share their thoughts. Ask them how their models might be unlike an actual fault and earthquake. For instance, the fault plane of their model is horizontal relative to the direction of gravity because of the way the model is arranged. In nature, such faults do not exist.

10. Ask students if they could predict the amount of displacement after each block motion and the amount of waiting time in between each block motion using their models. Allow students to use their models to answer this question. Have one student in each group operate the model. Make sure to ask the student to use the same steady motion when pulling the tape. Ask students if they are able to get regular periodic behavior out of their models when they keep all variables the same. The answer is no. This demonstrates that predicting earthquake is not going to be an easy task. If we cannot get regular behavior out of our simple models, it is very difficult to see it in the complex behavior of Earth systems.

11. Explain to students that quantitative measurement provides information in terms of numbers, proportions or other measurable quantities. Ask them to name some other kinds of quantitative measures (minutes, hours, and centimeters). Now ask students what aspects of their model can be measured quantitatively. Students can measure the displacement after each block motion using a ruler, and the timing in between each motion using a watch. Ask students if the steady pulling motion applied on the measuring tape by a student can be measured. What about the energy (or strain) in the rubber band?

12. Explain to students that scientists use a variety of methods to measure displacement along faults, timing between earthquake events, the motions of tectonic plates, and the stored elastic energy. These measurements help scientists to better understand earthquakes and earthquake prediction.

13. Finish the discussion by asking one student to give a definition of an earthquake using the information they learned from operating their models.

Reference

Hubenthal, M., Braile, and L., Taber, J., 2008, Redefining earthquakes and the earthquake machine, The Science Teacher, 75(1), p. 32-36, available online at http://www.iris.edu/hq/resource/redefining_an_earthquake_v12

Figure 1: Wooden blocks with screw eyes

Figure 2: Final model. Sandpaper is glued only to the bottom of block A.

Figure 3: A student operating the model

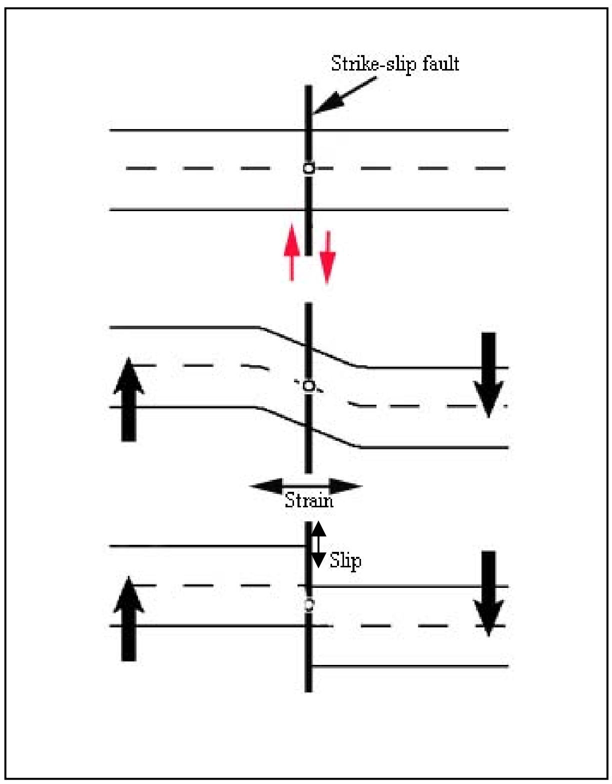


Figure 4: Illustration of elastic rebound theory. From top to bottom: Original position of the road; strain builds up while the fault is locked; then releases during an earthquake.

Lesson 6: Seismic Waves Supplementary information: 3-6

The earliest scientists first observed the waves that earthquakes produce before they could accurately describe the nature of earthquakes or their fundamental causes, as discussed in Lessons 1-5. Therefore, the earliest solid scientific advances in seismology concerned earthquake waves. As discussed in Lesson 5, earthquakes occur when elastic energy is accumulated slowly within the Earth’s crust as a result of plate motions, and then released suddenly at fractures in the crust called faults. The released energy travels in the form of waves called seismic waves. It is this released energy that puts human beings and human structures in danger. Therefore, it is critical to understand where this energy is released and in what form.

In this lesson, students learn about different types of seismic waves on the basis of where and how the waves move. In addition, students discuss how scientists use earthquake waves to investigate the interior structure of the Earth.

This activity is designed for one 1-hour class period.

Materials

A few Slinkys
1’ of white (or other brightly-colored) plastic tape
One 2 meter rope
One Brick
One hammer

Introduction

1. Ask a student to give a definition of an earthquake using the knowledge gained in Lesson 5. Remind students that earthquakes occur when elastic energy is accumulated slowly within the Earth’s crust as a result of plate motions, and then released suddenly along fractures in the crust called faults. Tell students that the released energy can travel through the Earth’s interior and along its surface, and that it can put human beings and human structures in danger.

2. Encourage students to discuss how they think the elastic energy travels to the surface of the Earth or whether they think it passes through the entire Earth. Use a simple example: Ask students to predict what would happen if they touch one end of a brick and tap the other end with a hammer. If you have a brick and a hammer, allow students to experiment with them. Students should be able to feel the energy of the hammer in their fingertips. Encourage students to guess why they can feel the energy. Explain to them that they can feel it because the energy of the hammer blows travels to their fingertips in the form of waves.

3. Explain to students that earthquake energy travels in form of waves. These waves are called seismic or earthquake waves. There are different kinds of earthquake waves: body waves and surface waves. Body waves pass through the interior of the Earth whereas

surface waves travel along the Earth's surface. Explain that earthquake waves move particles of material in different ways: compressional waves create a back and forth motion parallel to the direction of the waves whereas shear waves create a back and forth motion perpendicular to the direction of the waves.

4. Ask your students where they think the seismic waves of an earthquake originate. Students may answer: along the fault plane or at a single point along the fault. Introduce to your students these two terms: hypocenter (focus) and epicenter. The focus of an earthquake is where rock ruptures and slips, whereas the epicenter is the point on the surface of the Earth that lies directly above the focus.

Caution! While the first seismic waves radiate from the focus, later waves may originate from anywhere across the area of slip. Therefore, all of the energy of an earthquake is not always radiated from the focus, and for this reason, the focus of an earthquake is not always the only source of seismic waves (Wampler, 2002)

5. Encourage students to think about other kinds of energy that travel in the form of waves (i.e. sound, light, etc.). Explain to students when a train whistle screams, the sound they hear has moved through the air from the whistle to their ears in the form of sound waves. Explain to them that waves are disturbances that transmit energy from one point to another by causing periodic (back and forth) motions. The whistle causes the nearby air molecules to vibrate. As molecules begin to vibrate, they bump against each other, and cause the neighboring molecules to vibrate. When the molecules next to their ears start to vibrate, that is when they hear the whistle. Ask students if they can hear sounds in outer space where there is no air. The answer is no. Sound energy cannot travel through a vacuum because there is no medium to be disturbed or vibrated. Ask students if sound energy can travel through solids or liquids. The answer is yes. Sound energy can cause molecules in solids or liquids to vibrate. Ask students why sound energy can travel through solids faster than liquids. Explain to students that in solids, molecules are closer to each other, and can bump each other quicker.

Note! Some people may hear earthquakes when earthquake waves travel through the ground (e.g., from a rumble to a boom). This is because earthquakes can sometimes generate sound waves in the audible frequency range. The sound energy travels through the ground, but can also be transmitted into the air.

Procedures

1. Divide students into pairs or groups of four. Hand each group/pair a Slinky and some plastic tape.

2. Direct students in each group/pair to mark two spots on their Slinky near the center with plastic tape at the top of adjacent loops. Students mark the coils so that they can see the movement of energy along their length.

3. Have two students each hold one end of the Slinky for their group. Stretch out the Slinky to about 3-meters along a floor, table, or other flat surface. Have students take turns compressing about 10-20 coils, and then releasing them rapidly while they hold the end of the slinky, watching the energy wave travel the length of the Slinky.

4. After several repetitions, ask students to describe their observations of the coil and the tape: the coils move back and forth along the length of the Slinky as they compress and expand it. Ask students what kind of earthquake waves this Slinky motion resembles. The answer is compressional waves. Remind them that in compressional waves, particles of material move back and forth parallel to the direction in which the wave itself moves. As a compressional wave passes, the material first compresses, and then expands. P-waves (P stands for primary) are compressional earthquake waves that pass through the interior of the Earth. P-waves change the volume of the material through which they propagate.

Note! P-waves in the air are sounds. P-waves can move faster through the ground than the air, but not all of this energy is in the range of human hearing. When the sound waves are in the audible frequency range, some people may hear them.

5. Now tie one end of a 2 meter rope to the door knob of the classroom door. Ask one student to hold the free end of the rope in his/her hand. Ask the student to back away from the door until the rope is straight with a little bit of slack, and start to gently shake the rope up and down. Allow each student to create this motion. After several repetitions, ask students to describe the rope motion. Ask them what kind of earthquake wave motion this resembles. The answer is shear waves. Remind them that in shear waves, particles of material move back and forth perpendicular to the direction in which the wave itself moves. S-waves (S stands for secondary) are shear earthquake waves that pass through the interior of the Earth. S-waves don't change the volume of the material through which they propagate, they shear it.

Note! The motion of the rope due to shear waves is much easier to observe than the compression waves, but the shear waves travel more slowly than compression waves. In an earthquake, scientists can observe the arrival of compression waves before the arrival of shear waves using seismographs. You may choose to show a close-up of a record (seismogram) for a single earthquake event, and ask your students to point out different seismic waves. In addition, shear waves cause much more damage to structures since it is easier to shake surface rocks than it is to compress them.

6. Encourage your students to critically evaluate their slinky and rope setup. Ask them if they see any limitations associated with their setup. Ask them to compare and contrast their simple setup with actual vibrations caused by seismic waves traveling through the Earth or along its surface. For instance, seismic waves carry energy from the source of the shaking outward in all directions (not in one direction only as the setup shows).

7. (Optional) Both primary and secondary waves are body waves (pass through the interior of the Earth). Surface waves travel along the Earth's surface. Two examples of surface waves are Rayleigh waves and Love waves. Explain to your students that Rayleigh waves

cause the ground to ripple up and down (like water waves in the ocean before they break at the surf line) whereas the Love waves cause the ground to ripple back and forth (like the movement of a snake).

8. Ask the students to recall how scientists use seismic wave observations to investigate the interior structure of the Earth. This is similar to checking the ripeness of a melon by tapping on it. To understand how scientists see into the Earth using vibrations, one needs to understand how waves or vibrations interact with the rocks that make up Earth. Introduce to your students the two simplest types of wave interactions with rocks: reflection and refraction. Ask students to define reflection. They should be able to give simple examples like echoes or reflection in a mirror. Explain to your students that echoes are reflected sound waves, and that students' reflections in a mirror are composed of reflected light waves. Tell students that a seismic reflection happens when a wave impinges on a change in rock type. Part of the energy carried by the wave is transmitted through the material (refracted wave) and part is reflected back into the medium that contained the wave. Refraction can be demonstrated by dropping a coin in a bottle filled with water. The coin changes direction when it hits the water's surface and won't sink to the bottom vertically. In other words, the path of the coin refracts (changes direction) when moving from the air into the water.

9. Explain to students that seismic waves travel fast, on the order of kilometers per second. The speed of a seismic wave depends on many factors. Ask students to think about a few factors that can change the speed of a seismic wave (e.g. rock composition, temperature, pressure, etc.) Ask them to explain how these factors can change the speed of a seismic wave. Students should be able to answer these questions based on the knowledge they acquired throughout this lesson. Seismic waves travel faster in denser rocks; temperature tends to lower the speed of seismic waves; pressure tends to increases the speed.

Caution! The speed of a seismic wave generally increases with depth, despite the fact that the increase of temperature with depth works to lower the wave velocity.

Reference

Wampler, J.M., 2002, Misconceptions – A column about errors in geoscience textbooks, Journal of Geoscience Education, v. 50, no. 5, p. 620-623

Lesson 7: Liquefaction Supplementary information: 3-7

Liquefaction is a phenomenon in which the strength and stiffness of a soil is reduced by earthquake shaking or other rapid loading. Liquefaction can cause major damage during an earthquake.

In this lesson plan, students explore the effects of liquefaction when a damaging earthquake strikes by building a simple model. Students also discuss different ways to reduce liquefaction hazards.

This activity is designed for one 1-hour class period. This lesson is adapted from Beven et al. (1995).

Materials

200 g of well-sorted fine sand (sandbox sand)
One 0.25 l clear plastic cup
One pie plate
A sinker or a comparable small weight (at least 60 g)
Scissors
Newspapers to cover work area
Water

Introduction

1. Cover a table with newspapers, and place a cup of dry, well-sorted fine sand on the paper. Ask students if it is possible to build a structure using the sand only. The answer is no. The sand is dry and loose and it won't be able to hold any shapes. Introduce the term "unconsolidated" which refers to loose, uncemented material such as dry beach sand. The particles of an unconsolidated material can separate easily. Ask your students to think about different ways to make the sand grains stick together. One way to bind sand grains together is to mix it with cement and water which produces concrete. Introduce the term "consolidated" which refers to compacted and cemented material. The particles of a consolidated material do not separate easily and can hold shapes such as blocks, arches, and columns. These are some basic shapes that allow people to build structures of almost infinite variation.

2. Explain to your students loose sediments contain empty spaces or pores between grains. Sometimes, the pores between grains are filled with water. Give them an example they can relate to such as watering a flower pot. The empty spaces between dry sediments are filled with water when the plant is being watered. Introduce the term "soil saturation" which refers to soils in which the space between individual particles is completely filled with water. Explain to your students that this water exerts pressure on the soil particles, and that any application of an outside pressure on the soil pushes the soil particles apart.

3. Now, fill the plastic cup with loose, dry sand. Ask students to predict what happens to the sand particles as you gently tap the cup against the table. The tapping causes the sediment grains to settle together and become compacted. Ask students to predict what could happen if the pores are filled with water when they squeeze the sand. The sediment grains push the water out of the pore spaces as they move closer to each other, similar to when water is squeezed out of a sponge or cloth. Explain to students that during an earthquake, something different happens: The squeezing done by seismic waves occurs so fast that there is little time for the water to flow out of the way of the sediment grains. As sediment grains are pushed together, they push on the water that is trapped within the pore spaces. This increases the water pore pressure and causes the grains to separate as they are pushed apart. This is called liquefaction.

4. Explain to your students that liquefaction can cause major damage during an earthquake. Ask them to think about how liquefaction can cause damage, particularly to structures. Encourage your students to think about other types of damage triggered by increased water pressure due to liquefaction (e.g. landslides, collapse of dams, etc.).

5. Show to your students photographs of structures damaged by liquefaction.

Procedures

1. Divide students into groups of four. Designate a work station for each group. Each work station should have all the materials listed above at the beginning of the lesson.

2. Ask one student in each group to cut off about 5 mm from the bottom portion of the plastic cup, and invert the cup and place it in the middle of the pie plate, as shown in Figure 1. Ask the student to hold the cup firmly, and slowly pour the sand into the bottom of the cup to a level of 10-20 mm from the top. Level the sand gently using fingers. Do not shake the cup.

3. Ask a student to gently place the sinker onto the leveled surface of the sand, and slowly pour the water into the pie plate around the outside of the cup and sand.

4. Ask students to observe what happens. The water starts to move up into the sand cup slowly. Ask students to tell you when the soil is completely saturated.

5. Once the soil is saturated, ask one student to hold the cup firmly in place while another student gives the side of the cup several sharp taps. Ask students to observe what happens to the weight (sinker). The weight starts to sink into the wet sand. This phenomenon is called liquefaction. The increased pore water pressure reduces the contact forces between the sand particles, weakens the entire sand deposit, and makes it behave more like a liquid than a solid, hence the name liquefaction.

6. Ask students what the sinker and the sharp taps in this experiment resemble in real life. The sinker can be an occupied building erected on saturated loose sand or soil. The sharp taps represent a large earthquake. Initiate a discussion by asking students to think about the

effects of liquefaction on people, homes, schools, buried utility lines (gas, water, sewage), agricultural lands, medical facilities, fire stations, and materials that have been buried in the ground like poisonous waste. Explain to students that heavy structures can suddenly sink or shift due to liquefaction, just like the sinker in the above experiment. Buried material or lighter objects (like gasoline tanks) can shift and sometimes float to the surface during liquefaction (this can be tested by burying objects in the sand and observing the results).

7. Challenge your students to think about ways to reduce liquefaction hazards when constructing new structures such as buildings and roads. Initiate a discussion by asking them to think about ways by which the pore water pressure can be reduced. Densification of the soil and improvement of its drainage capacity are two important methods by which liquefaction hazards can be reduced. Ask students what they would do to modify the earlier experiment to test this. Students can densify the sand in the plastic cup by pressing it using their hands and/or making small holes in the cup to allow water to leave the cup. If time allows, let students test their ideas.

8. Remind students of the main factors of liquefaction: loose and unconsolidated sediments, water, and strong shaking. Having these in mind, ask them to think about where they are most likely to see liquefaction induced by an earthquake. Areas of land near rivers or close to sea level may be prone to liquefaction hazards. Examples may include coastlines, marshes, areas with artificial fills, and shallow groundwater.

Useful Internet Resources

This site provides the layperson basic information about the “what,” “when,” “where,” “why,” and “how” of liquefaction (University of Washington, College of Engineering): http://www.ce.washington.edu/~liquefaction/html/main.html

Watch a video about liquefaction (Utah State University): http://www.juniorengineering.usu.edu/lessons/earthquake/earthquake.php

References

Beven, R.Q., Crowder, J.N., Dodds, J.E., Vance, L., Marran, J.F., Morse, R.H., Sharp, W.L., Sproull, J.D., 1995, Seismic Sleuths-Earthquakes: A teacher’s package for grade 7-12 (second edition), American Geophysical Union and Federal Emergency Management Agency, FEMA 253, 364 p.

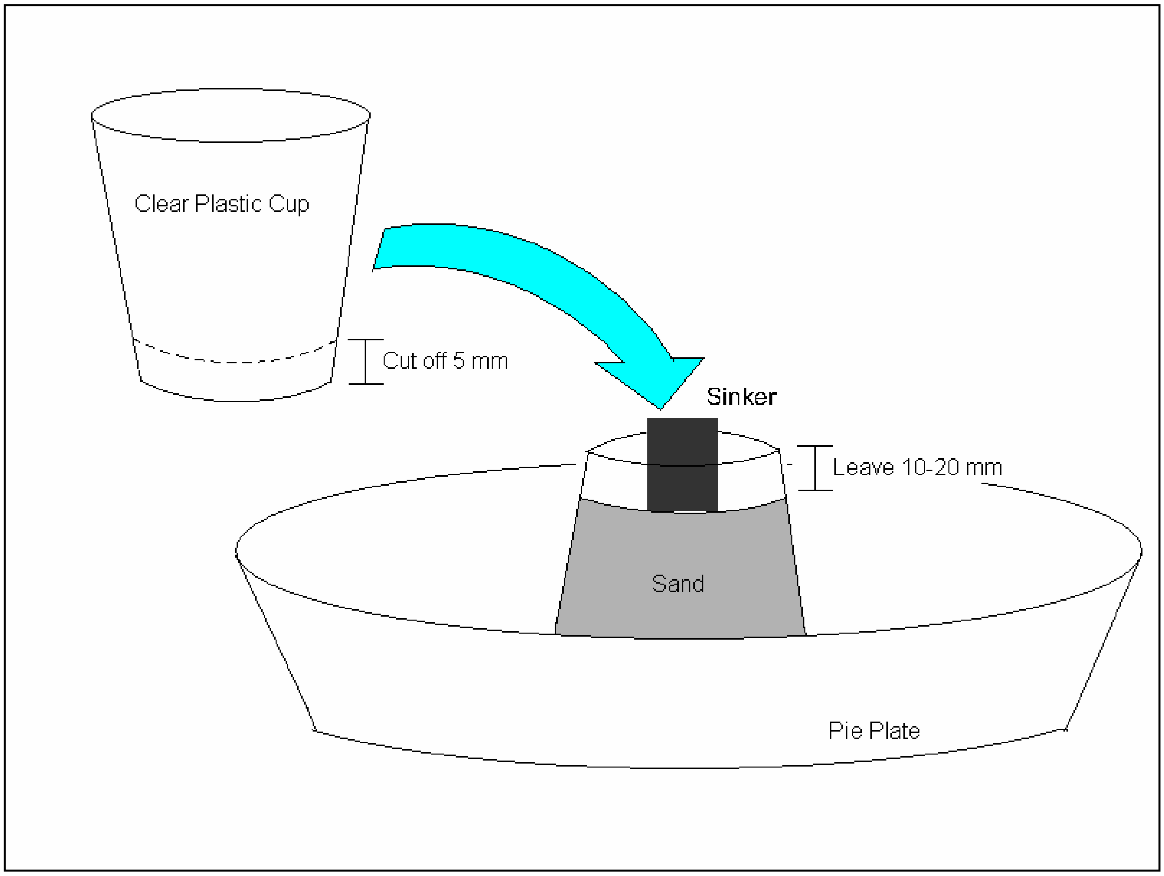

Clear Plastic Cup
Cut off 5 mm
Sinker
Leave 10-20 mm
Sand
Pie Plate

Figure 1.

Earthquakes are a major cause of landslides. Landslides occur when masses of rock, earth material, or debris flows move down a slope due to gravity. Landslides can occur on any terrain if the conditions are right, and cause significant damage and casualties to people and property. In this lesson, students learn about earthquake-induced landslides and the associated hazards, and how and why landslides occur. In addition, students discuss steps they can take to reduce landslide hazards.

Unlike previous lessons, Lesson 8 begins with a Tabletop Exercise. The objective of a Tabletop Exercise is to simulate a complex situation with multiple possible responses *before* the students have obtained all of the knowledge of the lesson concepts. The historical basis that served as the impetus for the Tabletop Exercise was the 2004 Southeast Asian tsunami, and the story of ten-year-old Tilly Smith. A British tourist traveling with her family in Thailand, she recognized the receding shoreline and strange surface bubbles from a tsunami lesson conducted just weeks before the event. She immediately warned her parents, who warned beachgoers and hotel staff of the impending tsunami. She is directly credited with saving hundreds of lives as a result of her timely and knowledgeable actions.

Introduction

1. Ask your students to describe and review what an earthquake is and what causes them. In addition to the direct effects of earthquakes such as ground shaking, ask them to list other hazards associated with earthquakes. Other hazards may include landslides, liquefaction, structural hazards (buildings collapsing), non-structural hazards (a falling bookshelf or a shattered window), and destruction of utility lines (gas, water, electricity) and roads.

2. Tell your students they are going to learn about earthquake-induced landslides and related hazards in this lesson. Show students pictures of landslides (for examples see pictures at the end of this lesson) and ask them to list what the photos share in common. Their list might include cliffs, ridges, steep slopes, rocks, trees, structures, people, etc. Encourage students to define a landslide based on what they see in the pictures. Explain to students that landslides are rock, earth, or debris flows on slopes that move due to gravity.

3. (Optional) Explain gravity to your students. Gravity is the driving force behind landslide flow. Gravity is the attractive force between all massive objects. It causes apples to fall from trees toward the Earth, stars to pull planets into orbits, and cannonballs that are thrown skyward to return to the Earth. Gravity produces the weight of an object, which can cause an object to move down an inclined surface. The resisting forces are forces that cause the landslide material to resist the downward pull of gravity. Two primary resisting forces in this example are frictional forces (discussed already in Lesson 6) and forces applied by the weight of the material (stress).

In general, the landslide driving force is most heavily influenced by the weight of the potential landslide objects and the inclination angle, as shown in Figure 1. When an object or group of objects rests on a horizontal surface with an inclination angle of 0 degrees, the pull of gravity produces no landslide driving force because all of the weight is pushing perpendicularly into the surface. The higher the inclination angle, the more dominant gravity becomes in ‘pulling’ material down the slope. This is because part of the weight starts to ‘pull’ the object in the direction of travel along the surface, as depicted in blue and labeled the Landslide Driving Force in Figure 1. Landslides begin to occur when the resisting forces reach a limit due to the strength of the material, the frictional properties between the slide material and the bedrock, or both. The resisting forces are depicted in red and labeled Landslide Resisting Forces in Figure 1. When the landslide resisting forces are equal in magnitude and opposite in direction to the landslide driving force, the object or group of objects will not move. When the landslide driving force becomes greater than the landslide resisting forces, the object will begin to move, which is analogous to a landslide in this setup. Triggering events such as earthquakes, heavy rain, or upsetting the inclined surface through digging can help to initiate a landslide, but gravity is always the primary force that enables any landslide to occur, regardless of how that landslide was triggered.

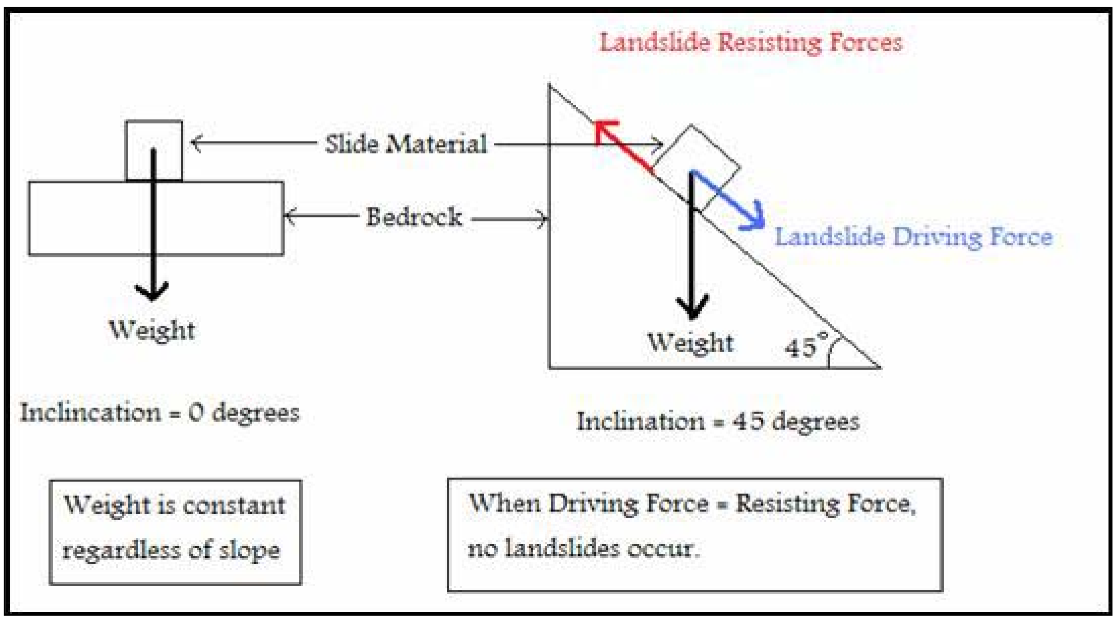


Figure 1. Diagram depicting the relationship between weight, landslide driving forces, landslide resisting forces, and inclination.

4. Explain to the students that there are three phases of landslide behavior: slope failure, transport of materials, and final deposition of slide materials. Ask them to look for where these phases take place in the photographs. Explain that slope failure can be gradual or sudden, and can exhibit noticeable properties such as visible cracks, slumps, or loud snapping sounds as slide materials break free from the bedrock or base material. Transport of materials can also be gradual or sudden, and can exhibit a wide range of transport modes such as rock or debris falling, rock or debris tumbling, material clump tumbling or sliding, fluid flow, or some combination of any of these modes.

Tabletop Exercise: Three Friends in a Valley

Note! This Tabletop Exercise specifically relates to the landslide hazards associated with earthquakes, however, landslides describe many different types of motion of sand, soil, mud, rocks, and other earth structures. Landslides occur in response to a wide variety of natural and man-made triggering events, such as earthquakes, heavy rainfall, volcanic activity, or road or building construction. There are more variations in landslide mechanisms and triggering events than can be covered in an introductory course. Therefore, the most important outcome of any lesson on landslides is that students develop the curiosity and willingness to critically evaluate what their surroundings can tell them about landslides.

Read the following scenario, stopping to ask questions and discuss the material with your students at the indicated points, or when students ask questions that are relevant to the discussion of earthquake hazards:

Three friends (Sara, Amira, and Gozen) live in the small city of Shahrabad, which is located in a beautiful mountain valley. The bottom of the valley has a small river running through it. The walls of the valley have land that includes forests and farms. The friends have lived there since they were young and they know that earthquakes sometimes happen there. They have only felt one small earthquake, but their parents and grandparents have told stories about some strong earthquakes that have happened in the area. Sometimes, during extreme weather like heavy snow or rain, the road that comes into Shahrabad from a nearby city is closed because rocks have fallen on the road or the road has washed away.

Sara and Amira live next to each other on farms located on slopes in the valley. Sara's farm used to have a natural spring that produced drinking water for both Sara's and Amira's families at a crack between two rocks, but the spring stopped producing water about a year ago. Recently, a neighbor has started complaining that some parts of his land have become very soggy and soaked with water, especially near the bottom of the valley.

Question 1: What are natural springs, and what are a couple of reasons why the spring on Sara's farm stopped giving water?

Potential answers: *Springs occur when water flows through cracks below the Earth's surface. The water can be a mix of rain water, water from underground channels that travel downhill toward the river, or water that is pushed up from deep underground in the deepest parts of the Earth that has not ever before been to the surface. Sometimes springs that are located very close to each other on the surface of the Earth have completely different paths that the water in each follows. The water that is soaking the neighbor's land may or may not be related to the water that used to come out of the spring, however, both of the changing events indicate that the land that Sara, Amira, and the neighbor live on is undergoing movements that may not be visible on the surface.*
The spring might have stopped because of some small change in the path of the water due to small movements of the ground, or because the source of the water has become empty. The changes in the path of the water could have occurred deep in the Earth or just a couple

of meters beneath where the spring is located. When the water flows through narrow cracks, very small shifts in the ground can stop the flow of water.

Sara's and Amira's farm share a wooden fence to keep their farm animals from wandering around. Sara and Amira often climb over the fence to play in the forest around their farm. About three years ago, they noticed that the fence posts were sloped at an angle at one spot in the fence near their path to the forest, and they were concerned that climbing over the fence was pushing the fence over. They changed their path so they didn't have to climb over the fence and then gradually forgot about the sloping fence posts. But the fence posts continued to tip over, little by little, without anyone noticing the low part of the fence. Until one day, about a month ago, a donkey got away by jumping over the low part of the fence. They helped their fathers fix the fence and straighten the fence posts so the donkey couldn't get away.

Question 3: What are some possible reasons for why the fence is slowly tipping over?

Potential answers: *There are many answers possible that don't relate to landslide hazards. The fence could be old and the wood falling apart. The donkey could be pushing on the fence to eat some tasty grass that grows outside of that part of the fence. But also, the ground could be moving very slowly beneath the farm, causing the fence posts to point uphill over the years. The fact that the spring stopped giving water may support this idea even further, especially if the path of the water to the surface was broken because the ground had shifted very slightly.*

Gozen lives down in the city in a house. Sometimes all of the friends gather there to have dinner and listen to the radio or watch television. From where her family eats dinner, they can see the river. Her father helps to build and fix pipes that move water for farmers in the valley, and he also helps to build and fix houses. A wealthy man has just built a house above a very steep hill that has a beautiful view of the valley, and he even paid just to have electricity from the city strung on wires up the hill to the house. But the rooms already have cracks in the walls on the side of the house near the steep hill. Some of the windows and doors have also become very difficult to open and close. Gozen's father has been working there the past few days and he jokes about how the wealthy man complains that his house was not built very well by workers from a nearby city.

Question 4: What are some possible reasons for the cracks in the walls? What are some ways to find out what is really happening?

Potential answers: *Again, the wealthy man may be right and the walls were indeed poorly built. Oftentimes, houses also settle naturally as they age and cracks form as the house comes to rest on the ground.*

However, the cracks are forming on the walls on the sides nearest the steep hill, which may indicate that the part of the house that rests on ground above the steep hill may be on unstable ground that is slowly creeping down the hill. Doors and windows can become difficult to open and close because the house is changing shape as the ground moves beneath it, causing the frames to become misshapen. Also, if the ground were naturally *unstable prior to building the house, the added load of the new house may be speeding the rate of movement of the creeping slope. Unstable ground or ground that is creeping is much more likely to release during a triggering event such as an earthquake or heavy rainfall.*

There are many ways to tell what the real cause of the cracks may be. Other indications, such as the bending of pipes, fences, footpaths, or roads can be found to see if the ground is moving. If the ground is shifting, then electrical wires attached to polls in the ground near the edge of the hill will become very tight as the polls move with the ground.

One day, the three friends decide to go play in the forest together. They travel farther up the hill than they had ever gone before. They find a very interesting bunch of very tall trees, whose trunks grow out of the ground at an angle before the trees turn straight and point up into the air like a normal tree, as in the figure below. Some of the trees have such a sharp angle that the girls can sit in the angle of the trees like a comfortable chair with their feet dangling down the slope of the hill! Most of the trees are curved in the same direction in the middle. The three friends name it the Sideways Forest.

Question 5: What would cause trees to grow like this?

Potential answers: *Trees always grow up toward sunlight, so presumably the trees initially grew at a different angle when they were young. The fact that the trees were all curved in the same direction, and that they were all located next to each other, might indicate that the ground beneath the Sideways Forest is all shifting in one direction. The trees are all much older than the girls, implying that the ground has been moving for a very long time. This might mean that the ground above the farm is unstable, and could be dislodged in the event of heavy rain, an earthquake, or human activities like road construction. Figure 2 shows the shape of a tree that may indicate a history of ground creep, when exhibited by groups of trees located together.*

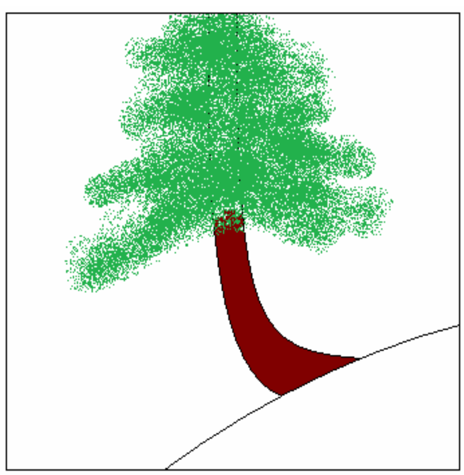


Figure 2. A common tree shape formed due to ground creep.

One day, while the friends are walking back home from school, there is an earthquake. It is strong enough to shake many of the buildings around them, and the earthquake is over after about a minute. They are just as far away from Gozen's home as from Sara's and Amira's farms.

Question 6: Where should the friends go first?

Potential answers: *There are many reasons to go to Gozen's house first. Gozen has a radio and television, so they can hear about the damage caused by the earthquake and whether emergency services are being delivered. The radio or television, if they are functioning immediately after the earthquake, may also have information on any developing weather system that may be coming in that could make the situation created by the earthquake even worse, such as heavy rain or snowfall.*

In addition, the combination of observations the girls have noticed around Amira's and Sara's farms indicate that the ground might be unstable and prone to landslide if another earthquake occurs. Knowing that the farmland is unstable, it is natural for the girls to want to make sure that their families and homes are safe. At that moment it is very dangerous to go there because the possibility for aftershocks is high. Since the girls are safe, they should make contact with a parent or family friend to let their parents know they are safe, and find out what has happened so that they can make an informed decision about what to do next, while conserving water, food, and medical supplies.

The families are all fine, and they meet at Gozen's house to talk about what happened. Through the radio, they find out that there has been an earthquake that has caused numerous landslides throughout the region. The neighbor whose land was becoming soaked with water reported that, in some places on his land, the surface had broken into cracks, and the smooth slope had become shaped like stairs. The road has been blocked by some falling rocks, but the families have some food stored away for when the road is closed. Gozen's dad says that many pipes have been broken in places so there is no water to be gathered through the city's water system. They send the friends down to the river to gather some water to support the families. While the three friends are at the river, they notice that the water level is much lower than it had been the day before.

Question 7: What are some possible causes for the low river water level, and what should the girls do about it?

Potential answers: *In river valleys that are likely to experience landslides after earthquakes, a sudden decrease in river water levels may indicate a landslide dam has formed upstream of the city. A landslide dam is when a landslide has blocked a river or stream, causing water to build up behind it. This causes flooding upstream and a drought or decreased water flow downstream. Landslide dams can be extremely dangerous because usually they are highly unstable. As the water builds up behind the dam, the landslide becomes saturated with water and can break catastrophically, flooding all areas* *downstream with little or no warning. Recall the instability of water-saturated unconsolidated materials observed during the liquefaction exercise in Lesson 7.*

The three friends should notify their parents or other city officials immediately of this possibility so that they can determine whether or not a landslide dam has formed. If action is taken quickly, the water behind the landslide dam can be released gradually before it builds up to dangerous levels. Even children can save entire communities!

The three friends told their parents immediately about the water level, who alerted city officials. A small landslide dam had formed upriver but it was not large enough to be a concern. All three families stayed at Gozen's house for a few days as aftershocks were felt, but none of them were as big as the original earthquake. While there had been no landslides that occurred on their farms during this series of earthquakes, the families became concerned about future earthquakes or other triggering events that could cause them to lose their farmlands and houses. They began to discuss ways of preventing landslides from occurring on their land.

Question 8: What are some of the things the families can do to prepare for landslides, and to prevent landslides from occurring on their land?

Potential answers: *Recognizing and communicating the signs of unstable land to city officials and neighbors in the community, and preventing further human development that can cause a landslide or put more lives in danger (such as building more human structures on unstable land) are the first steps to mitigating future hazards.*

Ask the students to make a list out of who they should contact if they suspect there is an emergency involving landslides. The game would be to rank the list in order of those that the students should contact first after an event or warning sign has occurred. Time and resources permitting, this ranking could be organized into a letter, sent to a local emergency services official, and evaluated for technical proficiency. The local emergency services official should be able to provide guidance about additional resources in the community that were not identified, and how students' responses and actions in an emergency can help or hinder the planned relief activities.

The second step is to prepare for future events by establishing safe, emergency meeting places in your community. People should also store food, water, blankets, and medical supplies in case emergency services are unable to reach them after for many days following an earthquake or landslide. The students will be taught how to prepare for emergencies in upcoming lessons.

The most difficult steps involve how to stabilize land that already shows signs of instability. Planting trees on otherwise open, exposed slopes may help to reduce water within soil that can trigger landslides more easily. Deep root systems of trees may help to bind loose soil and debris that would otherwise be easily released during a landslide. There are other, more costly engineering steps such as creating landslide barriers and ensuring proper drainage across roads that can be undertaken at the community level to mitigate landslide *hazards. Whenever possible, these steps should be coordinated with other community members to help reduce the costs and to ensure that everyone is aware of the risk of landslides.*

Tabletop Exercise Summary and Post-Exercise Discussion:

Many warning signs of unstable landslide-prone areas may be visible at the surface of the Earth. Now that students have completed the exercise, ask them to brainstorm about what evidence they would look for to indicate landslide-prone areas. Have them compare and contrast what they knew or did not know before the exercise started with what they learned as the exercise progressed. Emphasize that the point of this exercise was to put the students into a situation without any clear answers provided before the situation began, which is closer to how a real emergency situation unfolds.

Steep slopes, old landslide scars, and new cracks at the surface are the most obvious signs of the potential for landslides. Other subtle indications may include displaced fences, roads, or overhead power lines, leaning poles driven into the ground, new springs or water seepages in places that have never really been wet before, sticking windows and doors in houses due to shifting house frames, and unusual increases or decreases in creek water levels that cannot be attributed to rainfall or weather patterns.

Tabletop Experiment: The Homemade Landslide

Now that the students have simulated some common landslide experiences, they will have the opportunity to create, study, and describe a hands-on landslide demonstration. This simple experiment will permit students to observe the three phases of landslide development (slope failure, transport of materials, and final deposition of slide materials) and to explore the differences between the experiment and actual landslides.

Materials

Metal cookie or bread pans with 1-5 cm tall edges, about 40-60 cm in length and width
Pencils
Protractors
Sand
Soil
Gravel
Flat rocks
Cloths or paper towels
Newspapers to cover the working surfaces
Water pitcher with water (optional)
Toothpicks (optional)

Note! This activity can be done as an entire class with one pan or, with many pans and enough supervision, in groups. However, this activity can easily become messy, so it is not recommended that the class be split into more than 2-3 groups. The behavior of the sand, soil, gravel, etc. will depend on the particular properties of the materials that have been gathered. It is highly recommended that at least one educator go through all of the activities once before conducting the class to identify any problems with the setup, and to figure out methods of minimizing the mess created during certain parts of this activity. It may be necessary to move the activity outdoors, or to conduct all of the tilting experiments inside a large tray to catch water and spilling material.

Procedures

1. Cover the area that you intend to use for the demonstration with newspapers. Create a data table to record the results of your experiment runs (an example has been provided at the end of the lesson in Table 1). Encourage students to add new columns or to experiment with other materials that are not mentioned above, or to make remarks about behavior of the system that does not fit neatly into any of the categories.

2. Assigning duties: assign one student to be in charge of lifting one side of the cookie pan to create an incline as in Figure 3, telling the student to lift it slowly and smoothly, without shaking the pan or stopping, until the material on the pan begins to slide down. Assign another student to be in charge of measuring the angle that the cookie pan is at using the protractor. This student should call out the angle in increments of 5° when the material is not moving, and should call out the angle when the material moves (example: the material does not move until it reaches 23° where it begins to crack, then at 27° it collapses: the student would read out "5 degrees…10 degrees…15 degrees…20 degrees…cracking at 23 degrees [as it begins to crack], 25 degrees, collapse at 27 degrees [as it collapses]). This student should be concentrating on reading out the angle when significant events occur, while the remaining students make specific notes that describe what is happening.

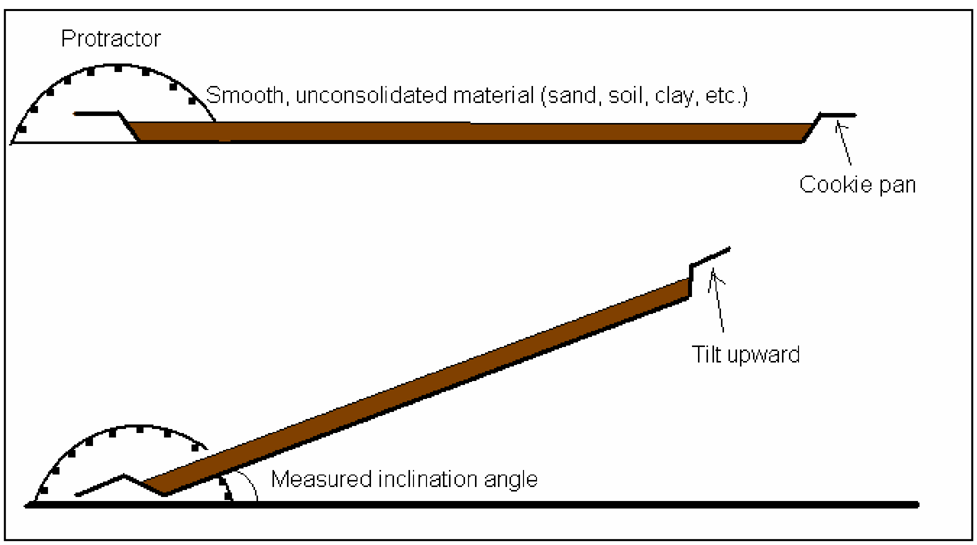


Figure 3. Side view of the cookie pan setup, protractor, and tilting orientation to produce a simulated landslide.

3. Start the experiment with the dry materials first, in order of those that are easiest to clean up (example: flat rocks, then gravel, then sand, then soil). Have the students complete the entries in the table that describe how the landslide simulation occurred. Have the students record details of the experimental setup before tilting the pan, such as what material was used, the dimensions of the pan, how deep the material sat in the pan. As the material begins to move when the pan is tilted, encourage the students to describe and note what happens in the data table at different angles, as provided in Table 1 below. After the materials have collapsed, have the students make note of *how* the material collapsed- did the material flow like a fluid, or did it travel in discrete blocks or slabs? Did it come to rest as a smooth pile of material, or were there small bumps or cracks in the collapsed material?

Complete the first run with all of the materials and discuss. If time permits, do more than one experiment for each material. When changing materials, use the cloths or paper towels to wipe off the cookie pan to make the conditions of the different experiments as similar as possible.

Note! The key to any scientific experiment is reproducibility. If the surface of the cookie pan is not regularly cleaned between different experiments, then the results might vary because of debris left on the surface from the previous experiments.

Discuss what happened with the students and encourage them to derive new questions about the setup. Were there any patterns? Which materials collapsed at the smallest and largest angles? Which materials collapsed quickly and which collapsed slowly? Were the materials that were used similar to materials that make up the mountains or hills around their region, why or why not? Could the students identify movements or behaviors in the materials that collapsed that corresponded to the warning signs that the three friends observed in the Tabletop Exercise scenario around their city?

4. Ask the students to predict what will happen if they repeat the experiments again, with the same materials, except that this time the pan will be tapped or gently shaken while it is being titled. Then repeat the steps above exactly as before for all of the same materials, but this time ask the student assigned to tilt the cookie pan to gently shake or tap the cookie pan as it is being lifted. Instruct the student to make sure that the rate at which the cookie pan is lifted is about the same as before. Instruct the student to keep the shaking motion about the same (in magnitude of motion and frequency) while tilting for all materials. Record any differences the students observe about the angles at which the materials collapse, how fast they collapse, the ways in which the materials collapsed, etc.

The overall result should be that the angle of collapse should be lower when the pan is shaken. Ask the students to describe why this should be the case, based on their knowledge of the weight, direction of gravity, friction, and angle of inclination angle. One answer is that materials like sand, when you view them very closely, are comprised of tiny little specks, each of which can be thought of as a tiny stone resting on many other tiny stones, surrounded by pockets of air called pore spaces (recall the liquefaction exercise in Lesson 7). When the students shake the cookie pan with pebbles on the slope, they tend to either roll down the slope, or to be pushed out directly away from the face of the incline, which causes it to ‘jump’ down the slope. When you add up the contributions from countless little stones that are all bouncing off one another, the net effect is that the entire mass of material is pushing itself down the slope as every little stone hops a tiny distance down the slope.

5. Finally, for each material, select an angle lying directly between the angle of collapse for shaking and the angle of collapse for the non-shaking case (example: the sand collapses at 15^{o} when shaking, 25^{o} when not shaking, so you should select the angle of 20^{o} for this case). Prepare each material in the pan and lift to the selected angle for that material. Ask the students what they believe will happen if the pan is shaken and why- the answer should be that it will collapse, because we are moving the material from a stable case to an unstable case by changing its environment. This is analogous to an earthquake-induced landslide.

Have the student shake the pan exactly as before, and have the students note the results.

Warning! The actual results may vary, but this is also part of the exercise. In some cases, the material will collapse as predicted, and in others, it may not. There are a tremendous variety of factors that dictate when, how, and why a landslide will occur, such as how compact the material sitting in the pan is, random variations in shaking the pan as it is tilted, and the random arrangement of sand grains at the contacts with the cookie pan, to name a few.

6. Summarize all of the observations made. Encourage the students to discuss the limitations of this setup when relating it to a natural environment, and have them identify some of the challenges earth scientists may face when trying to prevent landslides from affecting human communities. There are many possible answers: natural materials are not homogeneous, but a mix of different materials and consistencies. Natural slopes are uneven and irregular, with complex surfaces, cracks, and forces. The presence of water is also a complicating factor: for some materials observed with this type of setup, the water may increase cohesion and raise the angle of collapse. But in the real world, too much water tends to lower the angle of collapse due to the increase in pore pressure.

7. Encourage students to use their imaginations and the materials at hand with the sand, gravel, and soil materials to stabilize the surface. Some ideas include simply placing a wet paper towel over the surface. This functions very similar to surface netting and is a very effective, but somewhat expensive, way of stabilizing real surface cuts next to roads and buildings. Other ideas include building retaining walls using the flat rocks, or pebbles from the gravel, to hold back the material. Have the students experiment with different stacking arrangements and shapes at the base of the cookie pan as they tilt it upward, to see who can build the structure that best prevents landslides. Encourage students to find other materials around the classroom such as sticks, string, or pencils that may be incorporated into landslide barriers.

(Optional): Time permitting, have the students experiment with wetted materials. Have the students completely soak some of the materials in water for a few minutes (the longer the better). Have them load the cookie pan as before and note the results of raising the cookie pan. The results should be highly unpredictable. In some cases, the material will collapse at a shallower angle. In others, the material will collapse at a higher angle but the result will be much more catastrophic and sudden. The students can simulate rain water infiltration by *very slowly* pouring water onto the material at the top of the cookie pan as it is lifted. The students can also experiment with inducing an earthquake at various angles with wet materials.

Other optional activities include simulating the surface effects of creep by placing toothpicks, driven vertically into the sand, soil, or gravel materials, and slowly lifting up the cookie sheet as in previous steps. For some materials, very small movements of the material are reflected in the movement of the toothpicks readily before the slope collapses.

Useful Internet Resources

Engineering for the World:
http://www.engineering4theworld.org/

Much of the material used to derive the Tabletop Exercise and Tabletop Experiment can be found online at:
http://www.bechberger.com/Mel/Landslide_Activity/

Landslide 1

Landslide 2

Landslide 3

Landslide 4

Landslide 5

MATERIAL	INITIAL CONDITIONS	ANGLES	FAILURE AND TRANSPORT MODES (% MATERIAL REMAINING)	GRADUALLY, RAPIDLY, OR SLOWLY?	FLUID OR CLUMP DEPOSITION	NOTES ON COLLAPSE
Rocks						
Gravel						
Sand	1) 20 CM X 40 CM X 4 CM 2) DRY 3) CONSISTENT DEPTH 4) NO CLUMPS	15 DEG. 18 DEG. 22 DEG. 25 DEG.	SMALL SAND DEBRIS FLOW (99%) SMALL DEBRIS FLOW (90%) SMALL DEBRIS FLOW (50%) SAND COLLAPSE, DEBRIS FLOW (5% REMAINING)	SLOWLY & GRADUALLY SLOWLY & GRADUALLY GRADUALLY RAPIDLY	FLUID FLUID FLUID FLUID	SAND GRADUALLY RELEASED UNTIL COLLAPSE AT 25 DEG.
Soil	1) 20 CM X 40 CM X 4 CM 2) DRY 3) CONSISTENT DEPTH 4) SOME CLUMPING	26 DEG. 30 DEG. 38 DEG.	CRACKS FORM NEAR TOP OF MATERIAL, SLAB OF SOIL SLIDES (100%) CRACKS GET LONGER, SOME BUNCHING AT BASE OF MATERIAL (95%) CATASTROPHIC COLLAPSE, LAND AND DEBRIS FLOW (10%)	GRADUALLY RAPIDLY RAPIDLY	CLUMPS (1-5 CM) MOSTLY CLUMPS, SOME FLUID CLUMPS BECAME FLUID AFTER MOVEMENT	EXCEPT FOR CLUMPS AT TOP, SOIL SLAB WAS NEARLY CONTIGUOUS UNTIL COLLAPSE.

Table 1. A sample data table to record the initial slope failure, transport, and final debris deposition modes of the landslide simulator. This table was adapted from the description of the ‘Landslides to Seafloors’ activity found in the web folder listed under Useful Internet Resources.

Lesson 9: Structural Hazards

Supplementary information: 3-9

This lesson will introduce students to some of the basic concepts behind structural hazards in the context of earthquakes. Many cities have a variety of building sizes, shapes, architectural styles, and materials. This lesson covers the basic ideas concerning how structures respond to earthquakes using a tabletop exercise and three hands-on activities. The tabletop exercise consists of visual analysis of actual pictures taken in earthquake areas in Central Asia. The hands-on activities will explore how structures respond to applied loads.

In this lesson, the shake table activity is adapted from materials by Rathjen (2004). The wall model activity is adapted from Beven et al. (1995).

The tabletop exercise is expected to take about 45-60 minutes to complete. The hands-on activities are expected to take 2-3 hours total.

Introduction

1. Begin by reviewing with the students the two basic types of earthquake waves: P and S waves. Compare and contrast their differences (P waves are compressional, longitudinal waves and generally less destructive than S waves; S waves are transverse waves that move perpendicular to the path of propagation). Surface waves are a combination of both P and S waves that cause most earthquake destruction, because they cause wave-like motion along both the horizontal and vertical axes that cause structural damage. Please refer to Lesson 6 for more information about seismic waves.

2. There are three different types of applied forces (loads) that will be covered in this lesson: compression, tension, and shear. Compression is when a force is applied inward against the face of a structural element, shortening it. Tension is when a force is applied that pulls outward against the face of a structural element, stretching it (for example, as when a rubber band is stretched). Shear is when a force is applied in parallel to the face of a structural element, at an angle that is perpendicular to either compression or tension forces. Shape a piece of silly putty into a cylinder and have the students duplicate these applied loads, witnessing the deformation of the structural element. Remind students of Lesson 4 where they used a ball of pizza dough to demonstrate this. Inform the students that even solid structural pieces made out of steel or stone deform in these ways in response to loads, even if the human eye cannot discern the tiny displacement of the piece. A diagram of the different load types and the resulting deformation of the structural element is provided in Figure 1.

3. Some materials and shapes can withstand the different types of loads better than others. For example, stone materials can handle compression well, but because they are brittle they do not attenuate tension well. Most metals, such as aluminum and steel, can handle all types of loads well if they are properly shaped. As an example of this, a circular tube can handle loads well, but the slightest defect in the shape (such as a dent or hole) will greatly weaken the shape. To demonstrate this idea, begin with two identical cardboard

paper towel tubes. Take one of the tubes, bend it to a 90 degree angle, and then straighten it again to its original shape. Erect both tubes vertically on the flat surface of a table about 30 cm from each other. Now place heavy weights (such as large books) on top of each tube, one at a time. The tube that was bent will not support as much weight as the unbent tube.

4. Different materials can be used together to build structural elements that react well to all load types. Concrete, a stony material, can be used to build a structure with steel bars along its length so that during compression, the stony material carries the load, but during tension, the steel carries the load.

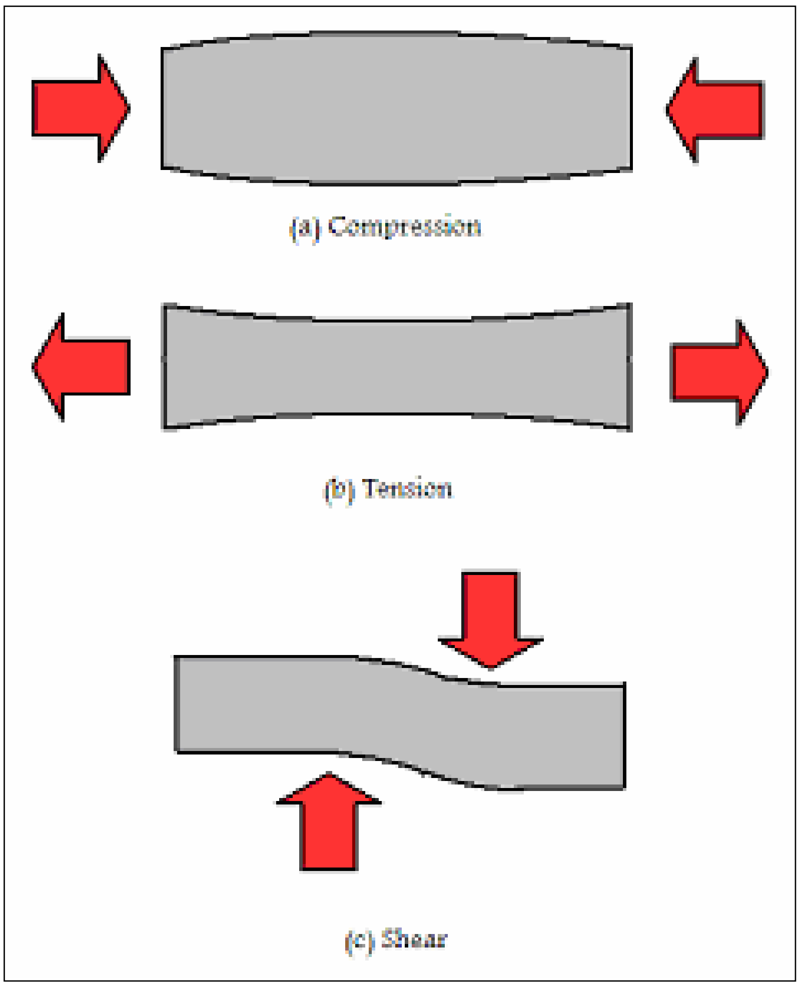


Figure 1. Different applied load types.

Tabletop Exercise: Uncle Architect

Note! This Tabletop Exercise was developed to help explain structural hazards associated with earthquakes. Structural hazards vary depending on the topography, geology, and architecture employed from region to region, as well as the workmanship and quality of materials used in individual structures. This exercise will explore some of the basic lessons that can be learned by observing actual structures that have survived earthquakes, and actual structures built in the aftermath of earthquakes.

Read the following scenario, stopping to ask questions and discuss the material with your students at the indicated points, or when students ask questions that are relevant to the discussion of earthquake hazards:

Sami lives with his family in a city. A very powerful earthquake has recently destroyed many parts of their city. Fortunately, Sami's family was prepared for the earthquake with some basic supplies (specifically, a first aid kit, some food and water, and a family/community communication plan; earthquake preparations will be discussed in detail in Lesson 11). Now that the earthquake has passed, many people are beginning the difficult task of rebuilding the city.

Sami's uncle, Mr. Jamali, is an architect and he has become very busy, with people coming to him day and night to get their home rebuilt, to make repairs to damaged buildings, or to make modifications to their existing buildings to survive the next earthquake. Mr. Jamali is so busy that many of his best assistants are overwhelmed with work, and he has asked Sami for help. Sami will begin as an apprentice to Mr. Jamali, and will be given tasks that will train him to recognize the best design aspects of buildings that allow them to survive earthquakes. Sami's first job is to make a survey of the buildings around the city that stood through the earthquake. He drove around the city with his brother, took many pictures and notes, and is now reviewing them to find any patterns.

At first, there were so many pictures that Sami didn't know where to start.

Question 1: What are some of the ways that the pictures can help Sami explore why some buildings can stand through earthquakes while others collapse? Why is it important to take notes that accompany the pictures?

Note! This question is intended to be very general and is designed to encourage students to be aware of the limitations of the information collection process. There are many different possible answers that may or may not have anything to do with structural hazards. Encourage your students to share their ideas, and if necessary, have them look at the pictures and accompanying notes to help them get some ideas to get started.

Potential answers: *Human memory and thought selectively focus on specific topics or items of interest, while pictures capture an entire scene. The pictures contain lots of information that humans may not be paying attention to right away, or that humans might* *need more time to process, therefore, they are a very helpful way of recording information about structures.*

It is important to take notes that accompany pictures because it is easy to forget where or when a picture was taken, especially if many pictures were taken in a single day. Pictures also do not record important information that may help to understand why a particular building survived, such as how old the building is, or whether the soil was wet or loose, or whether the building was built on a slope. These details may be important for forecasting future problems that buildings may experience, such as liquefaction (see Lesson 7) or landslides (see Lesson 8).

Sami decided to focus on pictures that showed buildings that stood through the earthquake next to buildings that collapsed partially or completely (such as pictures 1 through 6). That way, the strength of the earthquake and the composition of the soil that the structures are sitting on would be similar in the observed pictures. This helps to compare and contrast structures that collapsed or did not collapse during the earthquake under similar conditions.

Question 2: Compare picture 1 and picture 2. What is the same and what is different about the construction styles and materials? What are some possible reasons why the buildings in picture 1 did not fully collapse, but those in picture 2 did?

Potential Answers: *According to the notes, both pictures were taken near the ancient ruins of the city. Both buildings used bricks, but the ancient ruins used mud bricks and the old buildings used modern stone bricks. Yet the ancient ruins are much older than the buildings that have collapsed in picture 2, and have survived the earthquake without collapsing their roofs. Presumably, the ancient ruins have also survived other powerful earthquakes over the past hundreds of years.*

Some possible reasons: the ancient ruins used rounded arches to support the roof, while it looks like the newer buildings used straight walls and sharp angles, so arches and domes might survive earthquakes better than straight walls and box-like buildings. This idea is supported by picture 1, which shows that while the roof and connecting walls are still standing, the flat wall that is not part of the arches has collapsed. Alternatively, the ancient buildings in picture 1 may have been built with better craftsmanship than the buildings in picture 2. Sami should investigate these ideas by revisiting the sites and gathering more information before making any definite conclusions, though.

Sami, while looking through all of his pictures, noticed that he was focusing on just the buildings, but that there were more than just buildings that survived the earthquake.

Question 3: Look at pictures 3 and 4. What other objects in the picture, besides buildings, did not collapse during the earthquake? What features of these objects made them likely to survive, while other buildings collapsed? Are there other

hazards associated with these objects that are different from the hazards associated with buildings?

Potential Answers: *Anticipate many different answers from your students for these questions. Some of the objects include trees, electrical and telephone cable poles, cars, and signs.*

Trees are earthquake-resistant because they have a very deep root structure that anchors them to the ground, and they are well-balanced on all sides. Wood, as a material, is very strong and light-weight. However, while trees may survive earthquakes better than some buildings, trees can also produce falling branches during earthquakes and should not be sought for shelter unless absolutely necessary. In general, it is best to minimize the amount of material over one's head during an earthquake.

The telephone and electrical poles are also anchored in the ground, but sometimes not as well as a tree. They must support weight that can pull in the direction of the cable, so that any disruption in balance (i.e., caused by collapsing buildings, falling tree branches on the wires, etc.) can cause them to fall over. Cars and signs are very low to the ground and do not support any external weights, therefore they survive earthquakes very well unless they are crushed by something taller than they are.

Trees can produce falling branches. Electrical and telephone poles can bring sources of electrical shock down to where people are when they collapse. Cars have combustible fuel that can be released if something falls on them. Buildings should be designed to help reduce these hazards for people whenever possible.

Sami noticed that while the buildings in pictures 4 and 5 also used the stacking of stones and bricks like the building that collapsed in picture 2 did, much of these buildings are still standing while others around them are not.

Question 4: Look very closely at the buildings in pictures 4, 5, and 6. What is different about these buildings, and why would these differences help them to better survive earthquakes?

Potential answers: *If you look closely, you will see that the standing walls in picture 4, 5, and 6 are reinforced with steel, although the manner of reinforcement is different for each picture. Picture 4 shows an example of using steel cross-beams with brick-inlay walls. In the building in picture 5, the walls are made of cement and stones, and the non-reinforced front walls have collapsed. But the exposed surviving walls in picture 5 all show steel rods running throughout the wall (there are steel rods protruding from the front face of the upper wall. Steel rods can be seen running parallel to length of the walls on the lower floor in a couple of places where the cement has chipped or fallen away). In picture 6, a similar, smaller structure next to the large, standing building has steel protruding from the top surfaces, and perhaps was being built by the same people who built the large building behind it. It is evident from the wall exposed on the lower right side of the large building that it is not completely brick, but only brick inlay walls within* *a reinforced frame. The cracks on the upper floor of the bigger building on the right show where the frame has torn away from the bricks, even though the exterior paint is still intact.*

Steel reinforcement is very important in terms of strengthening brick or stone walls because it adds tensile strength (the ability to withstand tension loads). This means that the wall can be stretched (lengthwise or side-to-side) without breaking easily. Rocks and bricks can handle compression loads very well. However, a stone or brick wall, when stretched in response to a tension or shear load, will crack and collapse at much lower loads than they can withstand under compression. During an earthquake, vibrations stretch, compress, and shear all of the pieces of a structure. Steel is much more flexible material than stone. Therefore, the combination of steel with brick or stone means a wall can be compressed, stretched, and sheared and be expected to survive an earthquake.

Sami began to notice throughout the day that collapsing walls doesn't necessarily mean that the roof will collapse, especially when the walls are reinforced with steel. However, as Sami spoke with people around the city, he heard again and again that roof collapse is a serious hazard. Many people were injured, trapped, or killed when heavy roof materials fell on them as the structure collapsed.

Question 5: Compare pictures 7 and 8. What is different about the roofs of these buildings, compared to the roofs of the buildings in other photos? Why might these roofs survive an earthquake better?

Potential Answers: *The roofs of most of the buildings in pictures 7 and 8 are made of lightweight and flexible materials, namely wood and thin sheets of metal. The roof materials in the other pictures were primarily heavy, inflexible pieces of mud, brick, stone, or cement.*

Wood and metal are better than the heavy materials in earthquake-prone areas for many reasons. The most obvious reason is that when these lightweight structures collapse, the roof materials are much lighter, so they cause much less injury to people trapped inside the buildings if they collapse. In addition, because the lightweight materials are more flexible, they also keep their shapes when they fall during an earthquake. This means that there may be more empty spaces within a collapsed structure that people can survive in when the building collapses around them (by contrast, a stone or brick roof will tend to collapse into a pile with few empty spaces inside).

Sami visited a home that was being built by his uncle with a lightweight roof, but something about the way the beams were attached to the reinforced cement columns bothered him. He took pictures of these attachments and took them home to think about what was bothering him. While speaking to survivors of the earthquake, Sami learned that wooden walls, beams, and boards are shaken so much that they can actually shift side-to-side, or even bounce up-and-down at their attachment points as the earthquake occurs.

Question 6: Look at the close-up of the roof attachment in picture 8. What do you think bothered Sami about the way the wooden roof beam sits on the column? How would you design the column attachment differently for earthquake-resistance?

Potential Answers: *The wooden beams are resting on a flat surface on top of the cement column. If wooden beams and boards can shake side-to-side, back-and-forth, or up-and-down during an earthquake, it is likely that these wooden beams will be shaken off the top of the column, perhaps leading to collapse of the roof structure.*

One better way to design this attachment would be to create a groove or pit that the wooden beams rest in. This makes it far more difficult for the wood to be shaken off of the attachment point, and after the building stops shaking the wooden beam will come to rest within the groove, as shown in Figure 2 below.

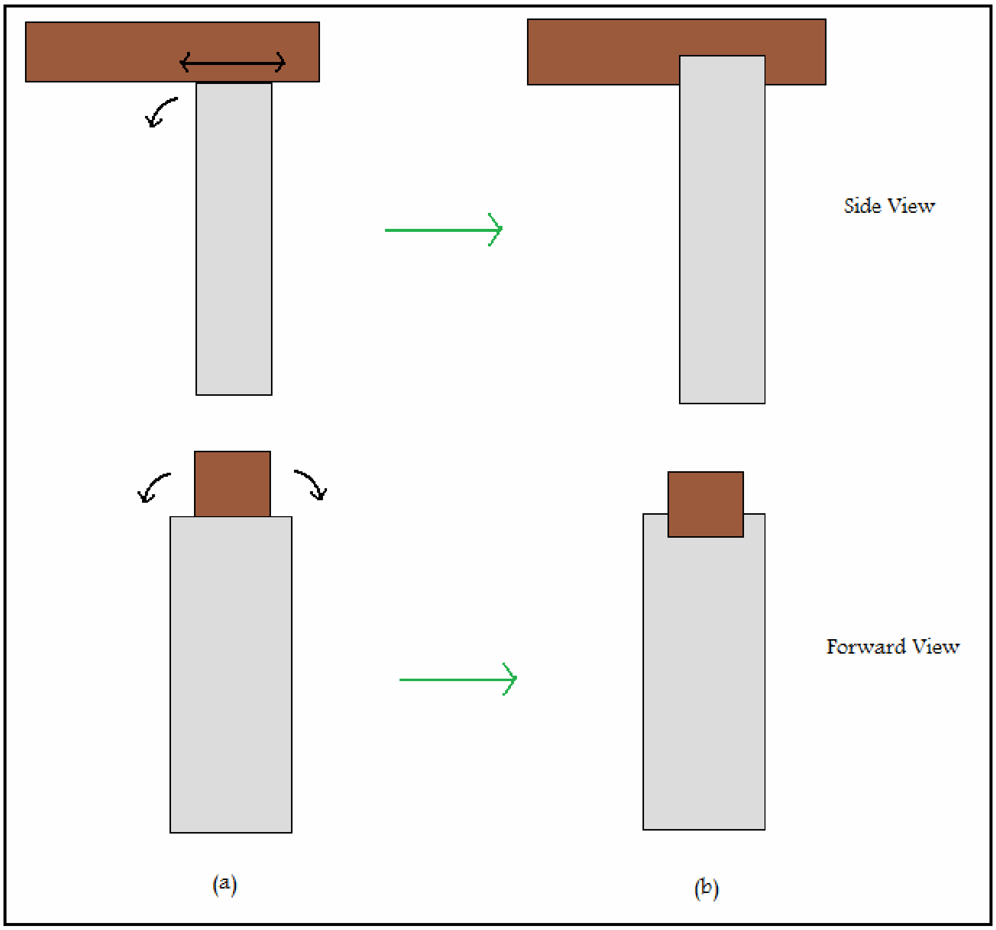


Figure 2. A diagram showing the mounting of a wooden beam on a flat column surface (a) and on a notched or grooved column surface (b). The black arrows show possible directions of movement during an earthquake that would cause the wooden beam to fall off the column in example (a), but these movements are constrained by the notches in example (b).

Tabletop Experiment: Building and Reinforcing Structures

Now that students have had a chance to observe and think about actual structures that have or have not survived earthquakes, they have the opportunity to explore structural hazards and mitigation techniques in the following 3-day lesson. On Day 1, students build model structures and describe what may happen to them when a load is applied. On Day 2, students build and test models on a shake table to understand how a structure reacts to vibrations of different frequencies, and explore the phenomenon of resonance. On Day 3, students build a model wall to learn how structural elements such as diagonal braces, shear walls, and rigid connections strengthen a structure.

Materials

DAY 1:
1 set of Styrofoam blocks, various sizes
Pieces of string, each 30 cm long
Paper clips
Toothpicks
A brick or a heavy item
A band saw (to cut Styrofoam)
Drinking straws
Straight pins

DAY 2:
1 Earthquake Shake Table – See: http://www.exo.net/~donr/activities/Shake_Table.pdf
1 set of wooden blocks, various sizes
1 set of Styrofoam blocks, various sizes

DAY 3:
Copies of Handout No. 1a and 1b (one per group- attached at the end of lesson)
<u>Materials for one model wall:</u>
21 jumbo craft sticks, about 15 cm x 2 cm x 2 mm thick
Electric drill with 3/16" bit
1 piece of thin wood (~2 mm thick) 45 cm x 6 cm (~18 in. x 2 in.)
1 piece of sturdy wood (2 x 6) for a base, about 45 cm (18 in.) long
16 machine bolts, 10 x 24, about 2 cm long (.75 in.)
16 machine screw nuts, 10 x 24
32 washers, #8
7 small wood screws
<u>Reinforcing elements for one wall:</u>
2 pieces of string, each ~25 cm (10 in.) long
1 piece of lightweight cardboard, ~15 cm x 15 cm (a little less than 6 in. square)
8 small paper clamps to fasten cardboard

Note! The shake table and model wall setups should be constructed and tested well before the lesson begins. It is recommended, whenever possible, that the students are involved in the construction of the setups.

Procedures (DAY 1)

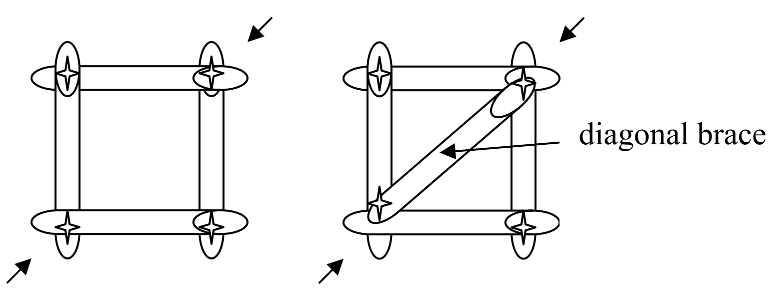
1. Divide students into small groups. Provide each group with pieces of Styrofoam, strings, paper clips, and toothpicks. Explain to each group that they are a team of seismic engineers, and are expected to build the strongest structure possible given the materials listed above for Day 1 activities. Tell them they have 20 minutes for this activity. This activity is designed for students to have some fun, and their efforts should not be criticized.

2. Ask each group to select a spokesperson. The spokesperson should bring the structure to the front of the classroom and describe it (i.e. why they built what they did).

3. Now ask all students to predict what would happen if you place a heavy item (like brick) on their structure. Explain to students that the heavy item simulates the static force of gravity (vertical load) that every structure must carry. Explain to students that Styrofoam is quite strong for its weight, so the heavy item can also represent the weight of all non-structural elements of a building (e.g. floors, wall coverings, electrical wiring, etc.). Explain to students that some building materials are strong, capable of supporting a lot of weight while others can be weak, collapsing if too much weight is placed on them.

4. Now ask students to predict what would happen if they shook the base of their structures. Allow them to test this gently on their structures. Encourage them to share their observations.

Note! Structures with triangular shapes may withstand the shaking better than square (or blocky) structures. Ask students why this may be the case. To enhance their understanding, provide each group with 4 drinking straws and four straight pins and attach them in the following manner (shape A):



A B

Ask students to grab the square by opposite corners and squeeze (shape A). They will notice how easily they can change its shape. Now ask them to add another straw (a slightly longer straw) connecting two opposite corners (shape B). Students should be able to note how the diagonal straw stiffens the structure. Tell them they have just created triangles and diagonal bracing to make a sturdier structure. This is because the applied loads (the force on the structure caused by squeezing the corners) either stretch or compress each straw in a triangle. Narrow structural pieces are strongest when stretched or compressed but they are weakest when they must bend, shear, or when the load is transmitted through joints. For shape B, the diagonal brace is compressed and carries most or all of the applied load, therefore the diagonal brace strengthens the structure.

(Optional) Ask the students to determine, without touching the structure, whether the diagonal brace in structure B above also helps to support the structure if the structure is squeezed at the other corners that the diagonal brace is not attached to (upper left and lower right corners)? Why or why not? After the students have discussed and formed a hypothesis, allow them to test their hypothesis using the model. The answer should be yes, it does support the structure even if it is squeezed at the corners that the diagonal brace is not attached to. In this case, the brace is stretched as the joints transmit the load throughout the structure. Since narrow structural pieces such as straws are strongest when they are stretched or compressed, the structure is still stiffened. Have the students discuss their answers and compare it to the behavior of the model.

5. Now ask them to predict what would happen if they held the base of their structures and pushed horizontally on the top. Allow them to test this gently on their structures, and share their observations with the classroom. Explain to them that buildings experience horizontal forces during earthquakes, and one way to simulate these forces is simply to push or pull a structure from the side. These forces cause compression, tension, and shear throughout the building structure, depending on how the structure is built.

Procedures (DAY 2)

1. Divide students into small groups. Provide each group with a set of wooden blocks. Ask each group to build a simple structure, but strong enough to survive the vibrations of a shake table. Explain to them they can use as many blocks as they want to build their structure. Allow 10 minutes for this part of the activity.

Note! You may want to explain to your students what a shake table is, particularly if they did not assist you with its construction. A shake table is a device that simulates an earthquake. Earthquake engineers and technicians use shake tables to observe how their building models respond to earthquakes. Show students the shake table they are going to use to test their structures. Allow them to take a close look at its components. Explain to them the purpose of each component. Refer to the link provided at the end of the lesson for detailed information about the shake table.

2. Now ask a spokesperson from each group to bring the structure to the front of the class. The spokesperson should describe their team's structure before placing it on the shake table. Encourage all students to predict what would happen to the structure when the shake table starts to vibrate. Explain that the motor speed is adjusted with the potentiometer, allowing the shake table to vibrate at different speeds. Ask the

spokesperson to start with a slow motion and gradually increase the motor speed. Ask all students to observe what happens to the structure. Allow all groups to test their structures.

3. Encourage students in each group to discuss why their structures collapsed or did not collapse. Ask them to pay attention to the height, weight, and shape of their structures when discussing the response of their structures to the shaking. Students may argue that tall buildings collapsed quicker than short buildings, or wide structures survived better than narrow structures. Ask students to predict what would happen if buildings of different heights are next to each other when vibrating due to an earthquake. Allow students to test this using two structural models side-by-side on the shake table. The building may hammer together or collapse on one another during powerful earthquakes.

4. Now is time for introduction to the concepts of amplitude, frequency, and resonance. Ask students what they already know about these concepts. Some students may know, for instance, that resonance and frequency are used in describing the tone of musical instruments and the quality of sound produced by different recording techniques and players. When explaining amplitude, remind students of what they learned in Lesson 6 (seismic energy). Amplitude is a measurement of the energy of a wave. In this activity, amplitude is how far to the side the block or structure moves. Frequency is the rate at which a motion repeats (or oscillates). In this activity, frequency is referred to the number of oscillations in an earthquake wave that occur each second or each minute. In earthquake engineering, frequency is the rate at which the top of a structure sways. You may want to draw something similar to Figure 3 when discussing the above terminologies. Resonance is an increase in the amplitude of a physical system (students' structure models, in this case) that occurs when frequency of table shaking is close to the natural frequency of the structures.

Define natural frequency for the students: the frequency of vibration (or oscillation) which an object or system of objects (a building for example) will exhibit according to its structural design and building materials. To help the students understand the idea of natural frequency and resonance, discuss instances of natural frequency that surround the students in their everyday lives. When a student is playing on a swing, the student is moving at the natural frequency of the swing/student system. When a friend pushes on the swing to make the student go higher, the friend is pushing at the natural frequency of the swing/student system. This causes resonance, so that every time the student is pushed, the student goes higher on the swing and the amplitude of the swinging increases. If the friend does not push at the natural frequency of the system, the student will not go very high in the air and resonance will be lost. The same effect happens to buildings during an earthquake. If the earthquake vibrations push on a building at or near its natural frequency, it will begin to resonate, causing the building to move with greater amplitude until some part of the building collapses or fails and the building falls apart.

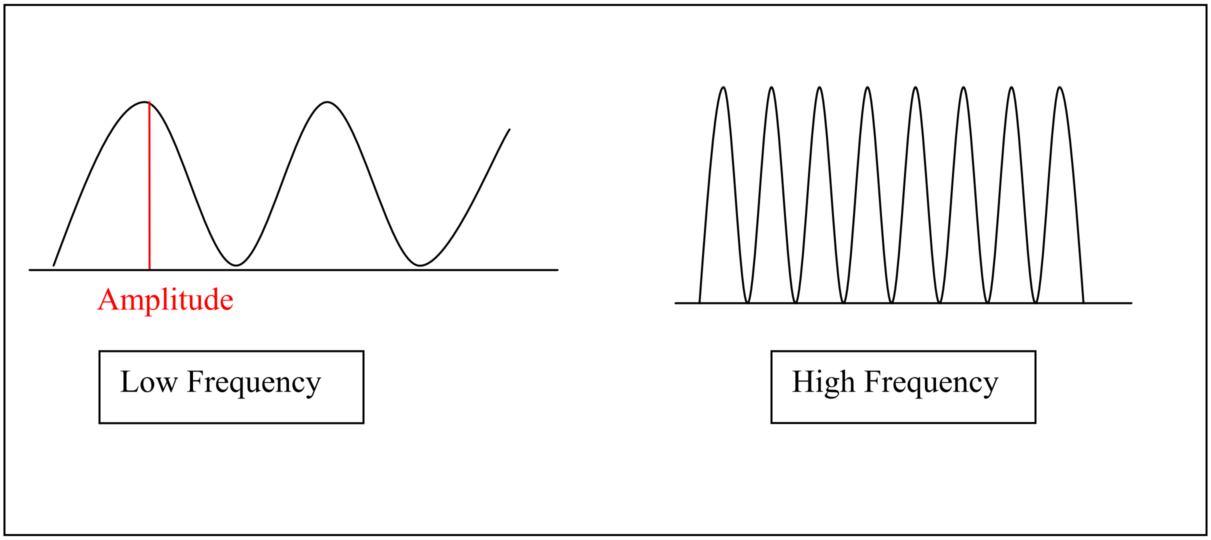


Figure 3. Amplitude of a wave, and high versus low frequency

5. Now draw a connection between the above concepts. Explain to the students that all objects or all structures (which are collections of attached objects) have natural frequencies. Explain that during an earthquake, buildings oscillate, and if the frequency of oscillation is close to their natural frequency, resonance may cause severe damage. Now place one of the wooden block structures on the shake table and encourage students to look for the presence of resonance as the table shakes. For particular motor adjustments, there may be certain places where the structure may be almost still, while at other places it vibrate widely. This may be true for only parts of the structure but not the entire structure. For example, a part of a structure may exhibit notable vibration at a particular motor adjustment while another adjustment (faster or slower) causes almost no vibration. It is also possible that one structure may topple under conditions that hardly cause another to vibrate.

Allow all groups to test their structures (or simply a wooden block) for new observations. To do so, ask a student to place a block so that it is standing vertically on the shake table. Have the student slowly turn through different frequencies using the control knob of the shake table. At lower frequencies, the block should not respond much. At a certain frequency, the block will begin to shake excessively and perhaps fall over. This is the natural frequency of the block. If the student turns through this frequency quickly enough, the reaction of the block will not be so excessive and the block may continue to stand even though the shake table is moving faster. Some blocks may have a natural frequency that is outside the range that the shake table can provide. Have the student attempt to identify the natural frequency of many different lengths of blocks, block structures, or other long, slender objects in the classroom that can stand on their own, in a similar manner. Allow plenty of excess time for the students to experiment with the shake table and their structures or blocks, and to ask and attempt to answer their own questions.

6. Explain to students that one way to protect a building from resonating with an earthquake is to isolate its foundation or base from the ground with devices much like wheels. This technique is called “base isolation” used by structural engineers who place

buildings on devices that absorb energy so that ground shaking is not directly transferred to the building (Figure 4). An appropriate analogy would be the relationship between automobiles and their suspension system of springs and shock absorbers, which cushion the occupants from a bumpy ride.

(Optional): If time allows, provide students with standard small wheels to be added to their models. Allow them to test their structures (with the wheels attached to their base) one more time on the shake table.

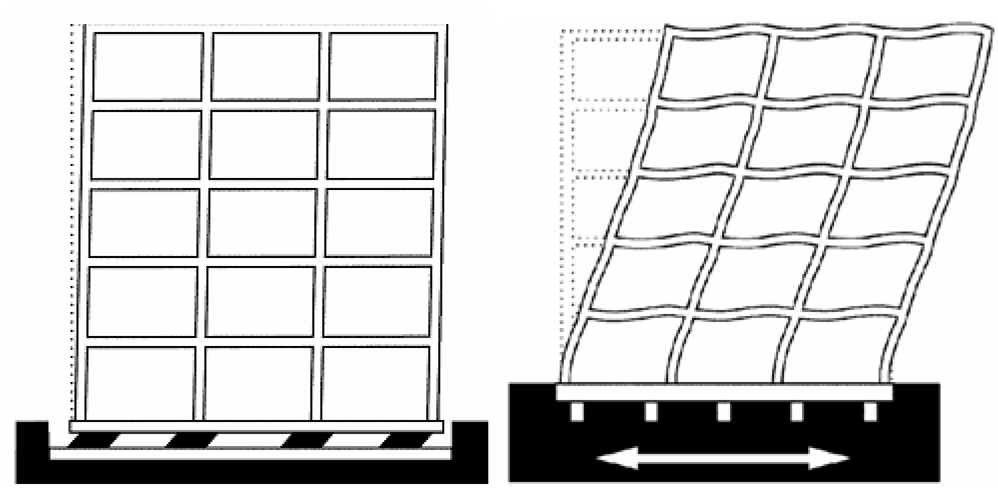


Figure4. Earthquake response of a base-isolated building versus a conventional fixed-based building (from: http://06earthquake.org/new-technologies.html)

To slow down structure oscillation and to dispel seismic energy, seismic engineers may also use dissipaters. These are devices mounted among some elements of the building. During an earthquake, dissipaters are subjected to movements which are relative to each other. Dissipaters slow down the vibration by dissipating viscous or friction energy when the structure oscillates.

7. Encourage students to think about other ways of reducing resonance in a building. Ask them what other structural elements they can add to their buildings that would allow them to better withstand earthquake loads. This topic is discussed further in Day 3.

Procedures (DAY 3)

1. Tell students they are going to assemble a model wall and predict what would happen if they push the base of the wall (simulating an earthquake). They are then given materials to reinforce their model and test again.

2. Divide students into small groups. Provide each group with enough material (base, craft sticks, screw nuts and washers) to assemble a model wall (Figure 5). Ask them to

make sure that the joints are just tight enough to hold the upright shape of the wall, but loose enough to be moved easily. You may choose to assemble one model and use it in front of the classroom.

Figure 5a. Model wall (front and back)

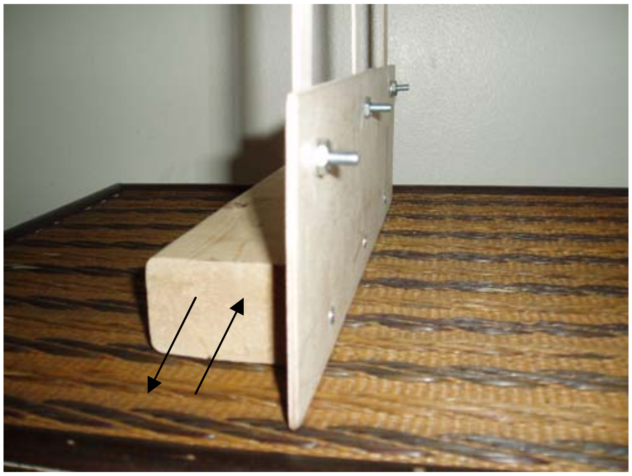


Figure 5b. Closer view of the base

3. Now ask students to describe the components of the wall, and ask them “what holds this wall up?” The answer is in the interaction of the vertical and horizontal elements to withstand the load of the structure. Explain to students what they refer to as weight will be called the force of gravity in this activity. Ask students to predict what would happen if you push the base of the wall side-to-side (as arrows show in Figure 5b.), simulating an earthquake.

Note! Earthquakes may cause ground shaking in many directions (see Lesson 6), but in this activity students model shaking in one direction only.

4. Instruct one student in each group to gently move the bottom of the model from the lower right or left side back and forth (as arrows show in Figure 5b.). When pushing fast, the model should collapse at the first floor only. Ask students why the other floors did not collapse. Ask them to point out where the weakest parts of the wall are based on the collapsed pattern. (The first floor collapsed because it was too weak to transfer enough horizontal force to move the upper stories. It could not transfer the shaking to the upper stories.)

5. Explain to students that pushing the base of the building is equivalent to applying force horizontally to the upper stories. Invite students to gently apply horizontal forces at different points on the model to simulate earthquake shaking.

6. Now ask students what could be done to strengthen the model wall. Students need to think about different ways through which the load can travel to the ground when strong forces act on the structure. Provide each group with pieces of cardboard, paper clamps, string, extra craft sticks, and a copy of Handout No. 1a and 1b. On the diagram provided in Handout No. 1a, ask each student to draw a force arrow (a vector) and trace the path the force takes to the ground. Review students' diagrams to ensure their understanding of the concept.

7. Now challenge students to design and build three different arrangements of the structural elements. Each time they modify the design, they must modify the diagram to show the new load path. Students must test the strength of their model walls to ensure survival of all floors when a force is applied. When a structure is reinforced well, students should be able to push on the upper story and slide the whole structure without any of the walls failing.

Note! There are many possible configurations that will produce a structure that can resist applied forces. However, the minimum configuration must include a continuous load path from the upper left hand corner down to the base of the structure.

8. Invite students to discuss the questions listed in Handout No. 1b. Ask one student per group to record each group's response. After all group finish the questions, have a spokesperson from each group present students' responses to one of the questions. Allow the class to come to some consensus on their responses to that question, and then proceed to another group until all the questions have been discussed.

Caution! Discuss with the students the similarities and differences between the wall model and what real walls experience during an earthquake. The primary difference is that earthquake surface waves shake buildings back-and-forth (horizontal) AND up-and-down (vertical), whereas this model only simulates horizontal forces. In addition, the shaking motion of an earthquake applies forces with changes in direction and magnitude in a complicated way, but this model is best for studying steady, unidirectional applied loads. Steady, unidirectional loads are also known as ‘static’ loads, whereas changing loads are known as ‘dynamic’ loads.

9. Explain to students that seismic engineers use similar methods to provide earthquake reinforcement for existing buildings. Engineers tend to use a combination of techniques to complement the strengths and weaknesses of each approach, which include use of diagonal braces, shear walls, and rigid connectors. Diagonal braces (craft sticks in this activity) are usually built into a wall to add strength. Shear walls (cardboard pieces in this activity) are added to a structure to carry horizontal shear forces. These are usually solid elements and are not necessarily designed to carry the structure’s vertical load. Rigid connections (paper clamps in this activity) do not permit any motion of the structural elements relative to each other.

10. Conclude this activity by helping students connect the behavior of their model walls to their mental images of real buildings during an earthquake. Emphasize that the back and forth motion, horizontal component of ground shaking is the force most damaging to buildings. Buildings are mainly designed to carry the downward pull of gravity, but to withstand earthquake shaking they need to be able to withstand sideways, or horizontal, pushes and pulls.

References

Beven, R.Q., Crowder, J.N., Dodds, J.E., Vance, L., Marran, J.F., Morse, R.H., Sharp, W.L., Sproull, J.D., 1995, Seismic Sleuths-Earthquakes: A teacher’s package for grade 7-12 (second edition), American Geophysical Union and Federal Emergency Management Agency, FEMA 253, 364 p.

Rathjen, D., 2003, Shake table, Exploratorium Teacher Institute, San Francisco, California, p. 1-4, available online at
http://www.exo.net/~donr/activities/Shake_Table.pdf

Picture 1. Ancient ruins of city. Mud bricks. Flat terrain. 200-300 years old.

Picture 2. Old part of city near ancient ruins. Standard bricks. 30-70 years old. Original building was 3 stories tall; only parts of back wall remain. The metal rods were not part of the original building that collapsed. Flat terrain.

Picture 3. Industrial part of city, across from the steel foundry. Standard bricks and steel shacks. Flat terrain. 10-30 years old.

Picture 4. North edge of industrial part of city, next to residential area. Only surviving building on block. Collapsed buildings were made of standard brick. Flat terrain. 10-30 years old.

Picture 5. Center of residential area. Collapsed front walls were stacked brick and stone mixed with cement and mortar. Remaining structural walls were all intact. Gently sloping terrain. 10-30 years old.

Picture 6. Eastern edge of residential area near the mountains. Flat terrain. All blue buildings built by same company with similar methods. Minimal structural damage, some small wall collapse. 10-20 years old.

Picture 7. Western edge of residential area near the river. Flat terrain. Brick building almost completely collapsed. Minimal structural damage to metal buildings. 10-30 years old.

Picture 8. Eastern edge of residential area near the mountains. Sloped terrain. New construction site (after the earthquake).

Handout No. 1a Name: ___________________

This chart was adapted from Beven et al. (1995).

Load Path with Additional Structural Elements
Use materials provided to add structural elements to your wall to provide paths for the horizontal forces, or loads, to travel through the wall

1. Push the third level of your wall. If the elements you added provided a load path to the base, the base of the wall should move. If they do not, the wall will fail somewhere. When you discover a setup that works, diagram it and sketch the load paths with arrows on the adjacent right column. Identify whether each element is experiencing tension, compression, or shear loads.	
2. Design and build another set of additional structural elements. Sketch the load path here. The base of the model wall should move when lateral force is applied to the top elements.	
3.Design and build a third set of additional structural elements. Use as few additional elements as possible. Sketch the load path and have your instructor check it. Test your load paths by removing elements not in the path to see if the building will stand up to a force.	

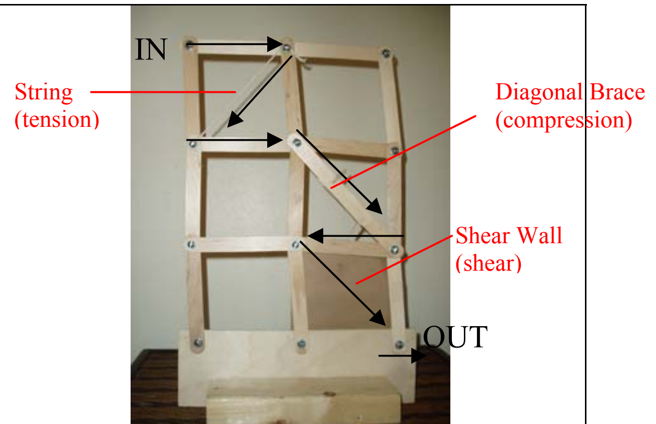
ANSWER KEY

Handout No. 1a   Name: ___________________

This chart was adapted from Beven et al. (1995).

Load Path with Additional Structural Elements

Use materials provided to add structural elements to your wall to provide paths for the horizontal forces, or loads, to travel through the wall

<table>
<tr>
<td>1. Push the third level of your wall. If the elements you added provided a load path to the base, the base of the wall should move. If they do not, the wall will fail somewhere. When you discover a setup that works, diagram it and sketch the load paths with arrows on the adjacent right column. Identify whether each element is experiencing tension, compression, or shear loads.</td>
<td>
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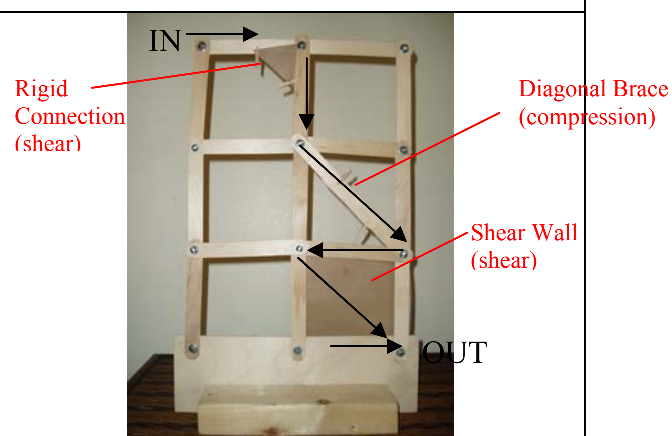
<tr>
<td>2. Design and build another set of additional structural elements. Sketch the load path here. The base of the model wall should move when lateral force is applied to the top elements.</td>
<td>
</td>
</tr>
<tr>
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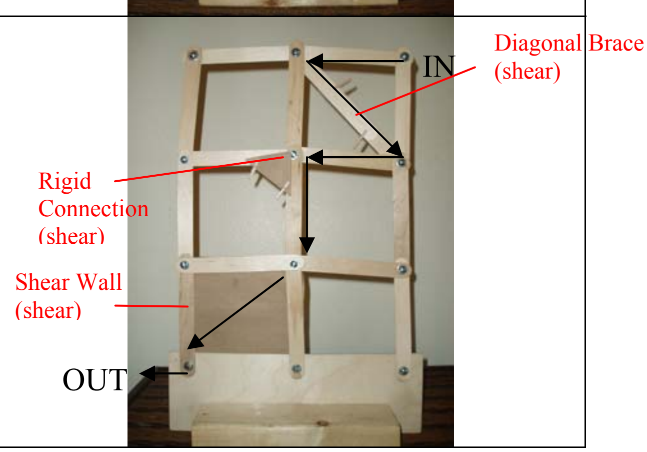
<td>
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Handout No. 1b Name: ___________________

These questions are from Beven et al. (1995).

Discuss the answers to the following questions. One student should write down students' responses to the questions.

1. What is a load path?

2. Why must additional structural elements be added to a wall before it can carry horizontal forces?

3. How many additional elements did you need to add?

4. Why doesn't the force take some path other than the one you diagramed?

ANSWER KEY

Handout No. 1b   Name: ___________________

These questions and answers are from Beven et al. (1995).

Discuss the answers to the following questions. One student should write down students' responses to the questions.

1. What is a load path?

The path that the load (force) follows through the structural elements of a building.

2. Why must additional structural elements be added to a wall before it can carry horizontal forces?

Normally, buildings only have to support a vertical force (gravity). When horizontal forces are applied, as in an earthquake, additional elements are needed to carry them.

3. How many additional elements did you need to add?

Each joint needed only one additional structural element. Only one joint on each floor is needed to carry a horizontal force that is transmitted throughout the entire wall, in this model.

4. Why doesn't the force take some path other than the one you diagramed?

The diagram shows the places that are strong enough to carry the load. If there were more than one place, the load (or force) would travel through both.

Lesson 10: Non-structural Hazards Supplementary information: 3-10

Many non-structural components in buildings such as furnishing and equipment, electrical and mechanical fixtures, architectural features (such as suspended ceilings), storage cabinets, shelves and glass may pose hazards when they slide, tip over, fall or collapse during an earthquake. The movement and collapse of these components may cause human injuries, fatalities, property damage, or even structural building failure in some cases. Therefore, it is extremely critical to identify and eliminate non-structural hazards. In this lesson, students learn to identify potential earthquake hazards associated with non-structural components of their school and residential buildings, and to provide recommendations for mitigating them.

The tabletop experiment is adapted from materials produced by Beven et al. (1995). The pictures used for tabletop exercise are from a report by the Educational Facilities Research Center (2005), National Institute for Educational Policy Research, Japan. The "bedroom safety activity" is from Field et al. (1995).

This lesson is designed for one 1-hour class period.

Introduction

1. Ask students to distinguish between structural and non-structural components of a building. Structural components of a building are non-decorative parts of a building that contribute to structural strength of the building whereas non-structural components of a building are not essential to structural design and do not contribute to structural strength. Ask students to name some structural and non-structural features. Alternatively, write down a mixed list of both features on the board and ask students to name which ones are structural or non-structural. Your list may include the following features: parapets, walls, vertical column supports, windows, foundations, floors, cornices, decorative overhangs, hanging light fixtures, appliances such as refrigerators or stoves, bookshelves, etc.

2. Ask students to imagine what their classroom would look like during an earthquake. Place several books on a desk, and ask a student to shake the desk. Ask students to describe what they observed. Explain to students that the books may slide and fall off the table during an earthquake, causing direct injuries and/or obstructing their way to the exit door.

3. Tell students that in this lesson they are going to identify non-structural features in their classroom that could pose hazards during an earthquake.

Tabletop Exercise: School Emergency!

Note! This Tabletop Exercise was developed to help explain non-structural hazards associated with earthquakes. Non-structural hazards vary from region to region and building to building, mostly depending on how the building is used, decorated, furnished, arranged, and maintained. This exercise will explore some of the basic lessons that can be learned by observing actual non-structural hazards documented within schools in Japan. In these areas, earthquakes are frequent and severe enough to warrant retrofitting of even seemingly benign and stable objects such as pianos and refrigerators.

Read the following scenario, stopping to ask questions and discuss the material with your students at the indicated points, or when students ask questions that are relevant to the discussion of earthquake hazards:

Three friends are joking with each other before they begin school for the day. They have been attending the same school for the last 3 years and know the building very well. They are each going to different classrooms for school activities this morning: Reza is going to the gymnasium for physical education, Farbod is going to the library to gather information for a science report, and Amin is going to chemistry class.

After class has been going for about 20 minutes, a rumbling noise can be heard. Reza doesn't even notice that the ground is shaking at first because he is having fun playing soccer. That's when he notices that people around him are confused and have stopped running. He feels the ground shake but it is not shaking very hard. Even the supervising teacher does not take any immediate actions. Aside from the slight shaking of the ground, there are only two notable indications that anything is happening at all: the lights in the gymnasium are swinging wildly, and you can see the tall trees just outside the gymnasium through the big windows shaking back and forth.

You, as a friend in Reza's gym class, go up to him and ask him what you think you two should do. Reza seems a little nervous but he tells you that since the ground is not shaking very hard, you two do not need to do anything since you are in no danger. He says the exit doors are located only 30 meters away if things get really bad. Reza takes the ball and scores a goal while everyone remains still during the earthquake.

Question 1: What are some of the early indications that an earthquake is occurring? What do you think about Reza's reaction in this situation? What are some possible reasons why Reza is telling himself that his reaction is the best? Would you follow Reza's advice or make your own decision? Why or why not? Are there any hazards present inside or outside the gymnasium?

Note! This question is intended to promote critical thinking about the situation itself (being in a gymnasium or other large room during an earthquake) and also to draw attention to the nature and limitations of decision-making processes that often occur between young friends in emergency situations. The overall goal is to empower each student to independently evaluate the situation, choose a course of action, and to make the best possible decisions that ensure their survival. This includes situations where students are given poor advice from friends or adults. The scenario has a variety of important details that can be discussed. Below is only a summary of some of the main points regarding earthquakes and non-structural hazards. Students are likely to point out a number of things about this situation that may not be covered below. Please discuss all comments that the students suggest, emphasizing the importance of maintaining situational awareness and critical thinking throughout the earthquake emergency.

Potential answers: *People are sometimes able to hear earthquakes when earthquake waves travel through the ground. P-waves are sound waves and while their tones are generally too low to be heard by humans, earthquakes can sometimes generate sound waves in the audible frequency range before any noticeable physical movement is noticed. Other indications include the shaking overhead lights and the shaking trees outside. Hanging or tall objects can be sensitive to small movements of the ground.*

Reza does not seem too concerned about the earthquake. While panic is not the best reaction, and it is generally said that it is a good thing to remain calm during a potentially dangerous situation, Reza seems a little too calm for this situation. One can be in a state of readiness and alertness about the situation without being panicked.

Reza might be saying these things because he was taught to think this way by someone, or because it seems reasonable to him based on his previous experiences with earthquakes that haven't been particularly destructive. Alternatively, Reza might be saying this because he doesn't want to seem like a coward, or to cover up for the fact that he is nervous and doesn't really know what to do.

Regardless of his motivations for behaving this way, and regardless of the actions (or inactions) of the teacher, Reza's suggested course of action is not advisable. No two earthquakes are ever the same, and just because other earthquakes in the area may have seemed similar to this one, and may not have caused much destruction, this earthquake could easily unfold into a larger earthquake with no warning. There is no way to tell whether this earthquake will be destructive before or during its occurrence.

There are many structural and non-structural hazards in this situation. While the earthquake does not seem powerful enough to destroy the gymnasium, there is no way to know this for sure. A small construction defect, or a resonance of the gymnasium structure, may induce large movements of the building or other fixtures within the room if the earthquake is producing waves near the natural frequencies of objects in the room (recall Lesson 9: Structural Hazards, for definitions of natural frequency and resonance). The lights swinging back and forth are a perfect example. If the lights become detached, they could easily fall, or the glass in the lights can break and fall down on students.

The trees shaking outside are also a potential hazard. They can produce falling branches, or the trees can swing over and hit the windows if they are close enough to them, causing the windows to break and shower glass inside and outside the gymnasium. Most glass windows are very brittle (recall Lesson 3: Properties of Earth Materials, for a definition of brittle) and will break free of their supports with only slight disturbances given their fragility. Glass windows can also break if the building itself begins to shift a small amount during an earthquake.

Because of these risks, in general it is best that the students leave the gymnasium as quickly as possible, taking care to avoid the large glass windows and trees outside if possible. Better to be safe, even if the earthquake is small, than to wait and see if a large earthquake is going to put the students in danger before they can react. Remind the students that during very strong earthquakes it is difficult or impossible to remain standing, let alone walk or run to safety. Even a short distance such as 30 meters to an exit or entrance may be a false comfort if the earthquake does become very strong.

Although these objects were not mentioned as part of the scenario description, there are other common objects found in a gymnasium that may cause a hazard. These may include suspended fixtures such as basketball hoops or volleyball net polls, or electrical fixtures such as large lights or loudspeakers.

Please reference Picture Group 1 to study actual scenes of damage within gymnasiums and other community areas in schools in Japan.

Farbod was in the library on the second floor of the school, studying for his science report. He liked being in the library during the summer because it is the only room in the school with a large air conditioner mounted in the window (the air conditioner helps protect the books during the hot summers from damage due to humidity and temperature changes that can affect the paper in the books). There was also a large TV on a rolling cart in the library near the door, which the librarian sometimes let Farbod use to watch interesting science videos that the library kept in the back room.

When the ground started shaking, Farbod didn't know for sure what was going on right away. He was in the reference section of the library, looking through the encyclopedias and map books. The first thing he noticed was that it felt like a big truck was going by outside, so he didn't give it much thought. Then he heard strange creaking noises from among the tall wooden bookshelves, as though somebody was standing on top of the bookshelf in front of him and trying to move it back and forth.

Farbod went to the end of the bookshelf toward the central part of the library, to see what everyone else was doing and to find out what was happening. He saw the librarian and other students looking out the window, trying to see if a big truck or airplane was causing the strange noises. They saw the trees shaking in front of the gymnasium and somebody yelled, 'It's an earthquake! The ground is shaking!'

Question 2: Is Farbod exposed to any hazards in the library? If so, what are some of those hazards? Is there anything Farbod should do in this situation?

Possible answers: Yes, Farbod is exposed to hazards in the library. He is exposed to the non-structural hazards in the library and any that might exist along the escape route through the school to get to a safe location. Farbod is on the second story of the school, which means he is also exposed to the structural hazards of being within a multistory building.

There are windows which can easily shatter during an earthquake, so the teacher and the children looking out the window are also exposed to hazards. In libraries, oftentimes the bookshelves are completely filled up with books, so that any slight movement of the bookshelves tend to cause books to fall off the shelves, or to cause the bookshelves to fall over. This may have been what caused Farbod to hear the creaking sounds among the bookshelves. Students should keep in mind that if just one bookshelf falls onto another bookshelf, this may cause all of the bookshelves to fall, one after the other.

There are also other hazards in the room, such as the large television on the rolling cart. The television is probably not secured very well to the cart, and the cart can easily move or fall over since it is not bolted to the ground. It is mentioned that the cart is near the door, which means that students can be harmed if the cart begins to fall over as they are leaving the room, or that the fallen television may get in the way of students trying to leave if it topples onto the floor before the students are able to leave the room.

Another hazard that exists for students outside of the building is the air conditioner that is mounted in the window. Often, these units are not well-secured to the building or the window frame. They are often balanced or perched in the window frame with little or no structural support. Air conditioners like this often fall out of windows onto the building or sidewalk below during an earthquake.

Farbod should be very vocal about the hazards that he sees for the teacher and students around him. In any earthquake, the best idea is to get into a safe location as soon as possible, regardless of the perceived strength of the earthquake. A slight shaking at first can very easily turn into a very powerful earthquake with little or no notice.

Please reference Picture Group 2 to study actual scenes of damage within libraries in schools in Japan.

After leaving his friends at the school entrance, Amin went to chemistry class. That day, they were studying a chemical reaction that involved heating of the reactants. Heating the reactants was always his favorite part of chemistry experiments. He also enjoyed delicately handling the reactants that could easily burn his skin if he were not careful. He was wearing eye protection goggles and a lab jacket to protect his clothes from the chemicals they were using in the class. Each group of students in the class had small flame stands (a Bunsen burner) at their table that hooked up to a gas tank in the back of the room through a series of tubes and valves, which could be seen running along the pipes and electrical wiring mounted near the ceiling in the classroom.

Amin was at the back of the room, washing the glassware that he was using to do the experiment, when he heard a noise that sounded like a truck going by. He also heard the tinkling sounds of the chemistry glassware in the cabinets around him. He kept washing his glassware but the sounds did not go away. His chemistry teacher then yelled, 'Earthquake! Students exit the school immediately. Assemble at the street corner in front of the school.' The teacher continued giving instructions as the students left: 'Move quickly but remain calm, do not take anything with you from the class and do not stop elsewhere in the school on the way out.'

Question 3: What are some of the hazards that the chemistry teacher must be aware of when conducting chemistry lessons in a high earthquake risk area? Why would the teacher tell the students not to take anything with them from the classroom? Compare and contrast the reaction of this teacher with the reactions of the previous teachers to the earthquake.

Possible Answers: The chemistry teacher needs to be aware of the numerous special hazards that are present in the classroom. If the chemistry glassware can easily fall out of the cabinets, then even a small earthquake would cause the glass to fall and break on the floor, which could slow or prevent some students from leaving the room (depending on the footwear that the students are wearing). If something falls on the gas tubes going from the gas tank to the flame stands throughout the room, then a leak could release gas into the classroom. This could cause a fire hazard, or could possibly cause illness or loss of consciousness of any trapped students if they are forced to breathe this gas. The teacher should have a fast means of shutting off the gas and securing the gas tank in an emergency, and the students should be educated in the location and use of these devices in case the teacher is not present or somehow unable to secure the room during an emergency. Any damage to the electrical wiring or pipes that are mounted near the ceiling could expose students to high voltage, or hot, cold, or waste water from broken or leaking pipes.

The chemistry teacher seems to have been prepared to respond to an emergency situation much better than the teachers that Farbod and Reza were with. The messages that the chemistry teacher yelled were clear, concise, and in descending order of importance: the problem was identified, followed by a simple command to move to a safe destination, and finally commands to make sure that the students did not stop until they reached the safe destination for any reason such as gathering personal belongings. While there may be some places in the school where the safest option is to shelter-in-place, a room with gas lines, pipes, electrical wiring, and glassware is not likely to be one of those places. The important point to note is that the teacher was prepared to recognize and act in a dangerous situation with clear instructions for the students. Students and teachers should be prepared to make the safest decision, in any part of the building, depending on the circumstances and layout of the school.

Please reference Picture Group 3 to study actual scenes of damage within special facilities of classrooms in schools in Japan.

Tabletop Experiment: Rapid Visual Screening (RVS)

In the Tabletop Exercise, students learned that it is important to independently assess the hazards of many locations within the school. They also learned that the safest option may be different for each location, depending on the structural and non-structural hazards present.

For this Tabletop Experiment, students will assess the hazards present in their classroom and at their home using the Rapid Visual Screening (RVS) technique. This technique is intended to be the first tool that enables a student to prepare for earthquakes by evaluating their environment for factors that contribute to earthquake hazards. Students will be encouraged to share the results of these assessments with teachers, parents, and other adults in their community to raise awareness of earthquake hazards exposure.

Materials

Paper and pencils
Chalk for the chalkboard or markers for the whiteboard
Copies of Handout No. 10a (earthquake non-structural hazards checklist)
Copies of Handout No. 10b (bedroom safety activity)

Procedures

1. Ask students to write down the name of one non-structural feature or an object in their classroom that could pose a hazard during an earthquake. On the chalkboard (or whiteboard) compile a list of hazards students noted. Ask students to explain why they considered them to be hazardous.

2. Divide students into small groups. Hand each group a copy of Handout No. 10a (earthquake non-structural hazards checklist) Explain to them that they have 15 minutes to work as a group to complete the checklist. Students should check yes or no for each of the items in the list, and skip any items that are not applicable to their classroom. Students in each group should then discuss the item that they have marked as hazardous and recommend a solution for reducing or removing the danger. If time allows, students should also discuss why their group has marked some features to be earthquake resistant. Allow students to add new items to the list when appropriate. Each group should select a spokesperson to summarize their observations and suggestions in a short classroom presentation. The presentation should not take more than 5 minutes per group.

3. Explain to students that they just conducted a rapid visual screening of potential hazards in their classroom, a common tool many experts use to assess the safety of structures and to develop plans to retrofit those structures for earthquake safety. Encourage your students to present their observations and suggestions for classroom safety improvement to their school's principle, and suggest that they volunteer to do all or some of the work. Explain to students that although identifying hazards and providing suggestions for mitigating them are critical steps towards their safety, students must

ensure that their concerns are heard by the right people and that their words have been taken into appropriate consideration.

4. Ask students to return to their groups. This time hand each group a copy of Handout No. 10b (bedroom safety activity). Ask students to compare and contrast the two rooms on the handout, and decide which room is safer during an earthquake and why. Build a classroom discussion around students' observations. Now encourage your students to develop a rapid visual screening checklist for their homes based on their screening of the classroom and the bedroom safety activity. Encourage students to this in cooperation with their family members, and prepare a report of their findings and of their suggestions for mitigating damage during an earthquake.

Useful Internet Resources

Guide and Checklist for Nonstructural Earthquake Hazards in California Schools (2003): http://www.documents.dgs.ca.gov/dsa/pubs/SB1122.pdf

References

Beven, R.Q., Crowder, J.N., Dodds, J.E., Vance, L., Marran, J.F., Morse, R.H., Sharp, W.L., Sproull, J.D., 1995, Seismic Sleuths-Earthquakes: A teacher's package for grade 7-12 (second edition), American Geophysical Union and Federal Emergency Management Agency, FEMA 253, 364 p.

Field, N., Schepige, A., 1995, Discovering earthquakes, Dog-Eared, Middleton, 40 p.

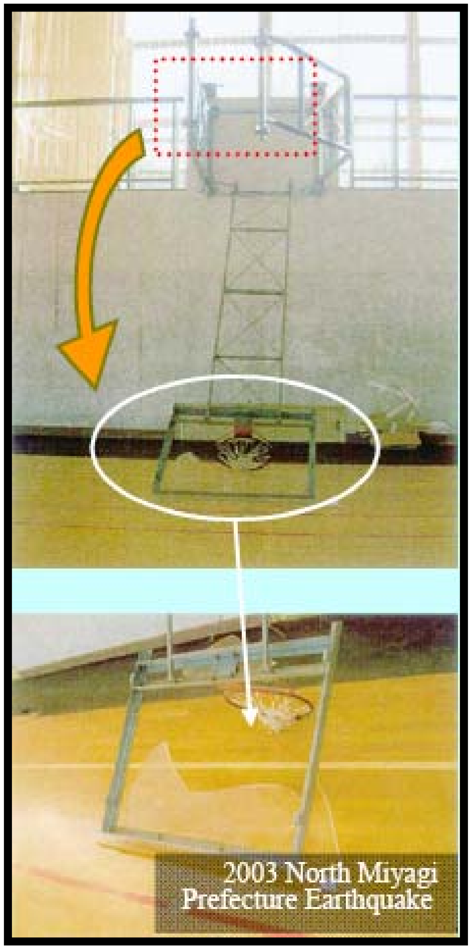
Case studies of Seismic Nonstructural Retrofitting in School Facilities" by Educational Facilities Research Center and National Institute for Educational Policy Research (2005), available online at: http://www.nier.go.jp/shisetsu/pdf/e-jirei.pdf

Picture Group 1:
Gymnasium and Community Area Damages

Top, left: Large, non-reinforced glass can easily shattered if mounted too rigidly to the building structure.

Bottom, left: Lighting and ceiling fixtures often shake loose during earthquakes, raining down on the floor areas below.

Right: Special items specific to sporting and community areas, such as sports equipment, loudspeakers, and signs can fall onto the floor areas below.



Picture Group 2:
Library and Shelving Damages

2003 Tokachi-oki Earthquake

2004 Chuetsu Earthquake, Niigata

(a) 2004 Chuetsu Earthquake, Niigata

Top, left: Unsecured bookshelves are dangerous, and the fall of one can cause the fall of adjacent shelves in domino fashion.

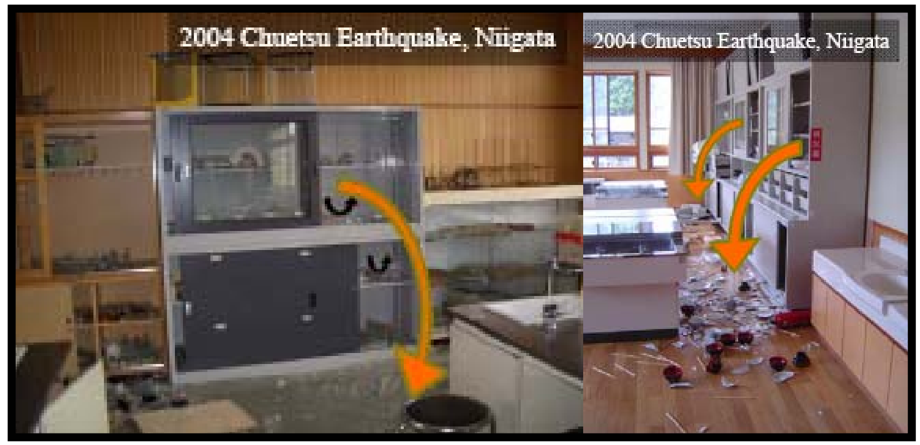
Top, right: An unsecured television on a top-heavy cart or shelf can fall over and slide across the floor.

Bottom, right: Window-mounted air conditioners are hazards for people on the street below.

2005 Fukuoka Prefecture West Offshore Earthquake

Picture Group 3:
Classroom and Special Resource Damages

2004 Chuetsu Earthquake, Niigata



2004 Chuetsu Earthquake, Niigata

2004 Chuetsu Earthquake, Niigata

Top, left: Track lighting can become loose if the mounts are not secured.

Top, right: Two instances of unsecured glassware shaking loose from shelving.

Bottom, right: Any material falling on unsecured or unprotected gas tanks or associated plumbing is a significant fire and explosion hazard.

1978 Miyagi-oki Earthquake (Photo: Nakano Lab., IIS, University of Tokyo)

Handout No. 10a: Rapid Visual Screening for the classroom

Group No. ________   Date: ________

Note! This screening survey may not be comprehensive for all classroom resources, layouts, and facilities. This screening survey contains reference to common hazards that are present in most classrooms, but may not reference or mention all the hazards that are present in your classroom. For completeness, this survey should be conducted in collaboration with an experienced engineer knowledgeable of earthquake hazards. For the hazards covered below, it is advised that specific comments be recorded adjacent to the checkbox to describe any peculiarities of the classroom that make the decision unclear.

This handout is adapted from Beven et al. (1995).

1. Are cabinets, bookshelves, and closets securely attached to the walls to prevent overturning?

☐Yes ☐ No

2. Are heavy items stored on the bottom shelves?

☐Yes ☐ No

3. Are books or materials stored on shelves have adequate restrains to keep them from flying off the shelves?

☐Yes ☐ No

4. Do cabinet doors have latches?

☐Yes ☐ No

5. Are television sets and computers securely fastened to work spaces?

☐Yes ☐ No

6. Are desks and chairs located where they cannot slide and block exits?

☐Yes ☐ No

7. Are all heavy and sharp objects/wall decorations/ hanging displays are securely mounted?

☐Yes ☐ No

8. Are laboratory chemicals or cleaning supplies secured so that they won't fall and spill?

☐Yes ☐ No

9. Are heavy furnishing or equipment on wheels protected against rolling?

☐Yes ☐ No

10. Are fire extinguishers securely mounted?

☐Yes ☐ No

11. Are the blackboards/whiteboards securely fastened?

☐Yes ☐ No

12. If there are potted plants or other heavy objects on cabinet tops, are they restrained?

☐Yes ☐ No

13. Are decorative ceiling panels or latticework securely attached?

☐Yes ☐ No

14. Are all the light fixtures secured?

☐Yes ☐ No

15. Are the fluorescent light fixtures resting on the hung ceiling grid or do they have other supports?

☐Yes ☐ No

16. Will hanging light fixtures swing freely without hitting each other if allowed to swing a minimum of 45 degrees?

☐Yes ☐ No

17. If there are suspended or decorative ceilings in the classroom, are they secured?

☐Yes ☐ No

18. If there are exposed pipes (water, gas, etc), are they secured?

☐Yes ☐ No

19. Do you see other hazards not included on this list? Specify.

☐Yes ☐ No

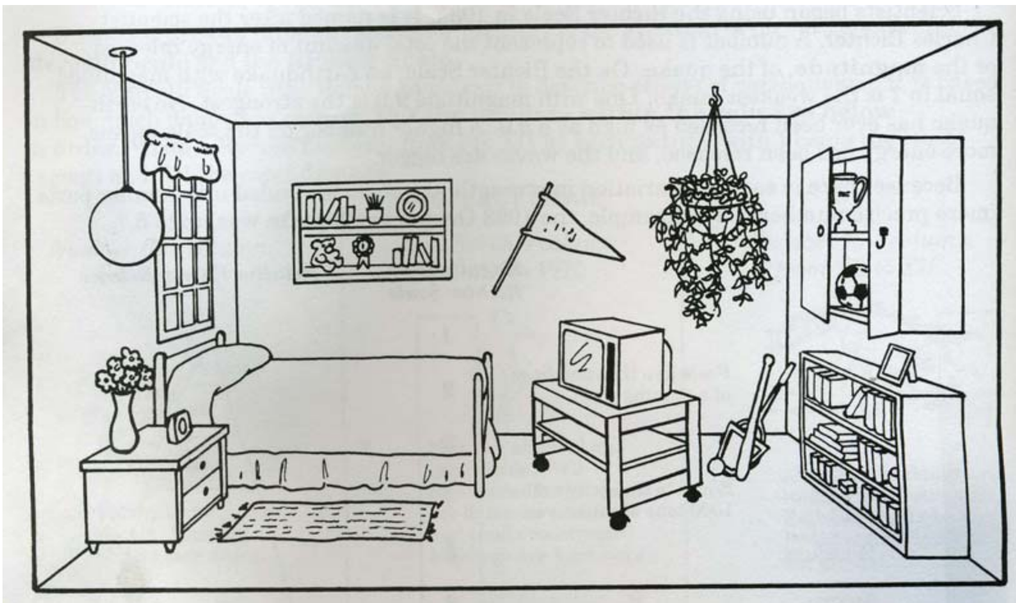
Handout No. 10b: bedroom safety activity

Name: ________ Date: ________

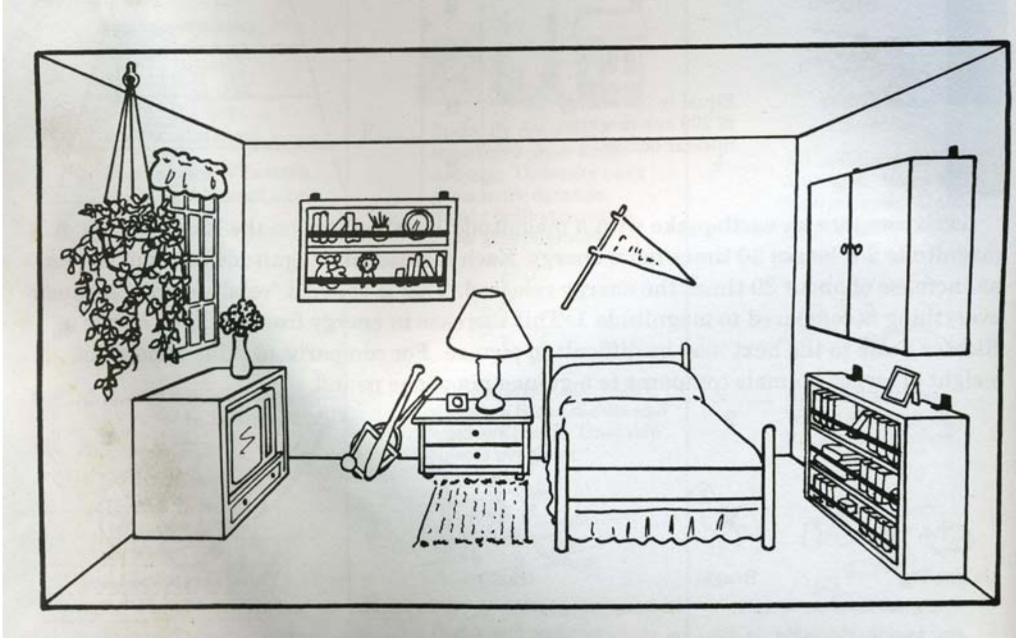
Safe or Unsafe?

Compare the two rooms on this page. How are they different? Which one is safer and why? What are the dangers in the other picture?

A



B



Lesson 11: Earthquake Drills, Plans, and Supplies. Supplementary information: 3-11

Recent earthquakes such as the 7.9 magnitude 2008 Sichuan Earthquake and the 7.6 magnitude 2005 Kashmir Earthquake demonstrate that many communities do not have earthquake-resistant schools. Many of the schools that collapse and kill children are modern and are sometimes situated near older buildings that withstand earthquakes. The collapse of schools in earthquakes can be attributed to poor construction and maintenance (discussed in Lesson 9). However, most injuries and deaths are often caused by falling of non-structural elements (discussed in Lesson 10). In Lessons 9 and 10 students learned to identify structural and non-structural hazards in their school and home, and how to mitigate damage. In this lesson, students learn to recognize the importance of advance planning for their school's emergency response and to prepare an emergency response plan for their school. In addition, students get to test, evaluate, improve, and present their emergency plan to appropriate authorities. Planning, reviewing, training and testing are critical components of an effective emergency response plan that can quickly return a stricken community to a normal state of affairs. The ultimate goal of this lesson is to highlight the importance of advanced earthquake planning and practicing.

Note! This lesson provides guidance for conducting and preparing an emergency response plan and drill regimen in a school. However, contributing factors such as a school's locality and its structural strength play an important role in determining the most effective emergency response plan for the school. For this reason, this lesson by no means provides a complete or appropriate guidance to emergency plan preparation for every school. Whenever possible, have the emergency response plan developed in this lesson reviewed by appropriate school authorities, emergency specialists, research scientists, administrative planners, and other members of the community (e.g., fire chief and pubic health administrators).

Note! It may be best to conduct this lesson before or after school, when there are few other school students present to disrupt or distract from the activities. In some cases, this lesson may be completed during class time when there are no students in the hallways, but it must be done quietly. The drill should be coordinated with the knowledge of school officials to prevent falsely alarming other students or educators that may be present.

Allow 2 two-hour blocks for this activity.

Materials

Basic maps of the school (roughly one map per 3-6 students)
Colored pencils
Notes from lessons 7-10 (specifically, the students' list of non-structural hazards)
Video camera equipment (optional)

Introduction

1. Begin by asking students to think about the best ways to respond rapidly to a dangerous situation (e.g., fire breakout, severe weather, poisoning, etc.). Explain to students that detecting

and recognizing the early signs that a dangerous situation is developing, in conjunction with practicing a well-developed response plan numerous times, are the best means of ensuring a safe, rapid, and appropriate response. Ask students to list some early signs of an earthquake. Some early signs may include light shaking of sensitive objects such as hanging lights or glassware, sounds such as rumbling or the movement of joints within the surrounding building, or in some cases erratic behavior by animals with a keen sense of hearing such as dogs or horses. Explain to students that recognizing early signs of an earthquake and initiating an immediate response is critical since the ultimate intensity of an earthquake cannot be determined before or during its early stages.

2. Tell students they are going to develop and test an emergency response plan and an earthquake drill for their school in this lesson. Ask students to explain the difference between an emergency response plan and a drill. Explain to them that an emergency response plan is a comprehensive plan that incorporates as much information about what to do in an emergency as possible, including safe routes to follow, structural and non-structural hazards, helpful resources, meeting places, and key emergency personnel for a particular location such as a school. The purpose of this comprehensive plan is to describe and support as many practical responses as possible for a variety of circumstances, and to serve as a guide for conducting earthquake drills. An earthquake drill is one set of simulated emergency circumstances, designed to test the ability of school members to make the most appropriate decisions to ensure their safety. The school members should understand the emergency response plan sufficiently to react appropriately during the drill.

Explain to students that with careful planning, it is much safer to over-react to a minor tremor than it is to under-react to a major earthquake, since a minor tremor provides a convenient opportunity to test drill response times, gathering locations, efficiency of movement, ability to handle secondary hazards (i.e., fires, broken pipes, non-structural hazards, etc.) and emergency supply availability. The goal of any drill regimen should be continuous practice, assessment and improvement.

Note! There are few standard guidelines to producing a well-developed earthquake response plan, since circumstances and hazards vary substantially by region, city, and building or location when an earthquake strikes, but one cardinal rule is: ACT EARLY, ACT FAST, DON'T PANIC!

Tabletop Exercise – Emergency Response Coordinator Team

Before beginning this exercise, please have a basic, unmarked map of the school prepared for the students. There should be at least one map for each group of students that will be helping to write the emergency response plan. The map should include a basic layout of the school including hallways, rooms, doors, windows, and escape structures such as emergency ladders (if any). It will be the students' responsibility to use this map to outline an emergency response plan.

The students have just graduated from university and earned jobs as Emergency Response Coordinators (ERCs) for their country, specializing in emergency response at schools. As part of their job, they have the opportunity to travel from school to school all across the country, developing effective earthquake drills that take into account the particular hazards that students at the school might face during an earthquake.

Note! It may be best to conduct this final activity before or after school, when there are few other school students present to disrupt or distract from the activity. In some cases, this activity may be completed during class time when there are no students in the hallways, but it must be done quietly.

Question 1: What are some university disciplines that might be helpful for completing this kind of work? Why might a government choose to pay for Emergency Response Coordinators versus responding to earthquakes after they have occurred?

Possible Answers: Many different disciplines are helpful for supporting the work of Emergency Response Coordinators. ERCs need technical specialists such as people with a background in geosciences, engineering, or architecture so that the latest geohazards data can be interpreted in the context of earthquake hazard detection and quantification. Trade specialists such as carpenters or nurses understand how earthquake response plans and mitigation techniques affect the management of emergency supplies and earthquake-resistant structures. ERCs may also need linguists who can translate the work into multiple languages if there are many ethnic groups in seismically active areas across the country. Almost all government groups require accountants and planners to ensure that government money does not go to waste through poor planning. Finally, earthquake education specialists may be required to effectively communicate the causes, effects, and mitigation techniques of earthquakes to all parts of society, including children, working parents, and the elderly, who may not otherwise have any contact with earthquake planning efforts.

A government may choose to pay for ERCs because prevention is the best way to save lives and avoid costly property damage before an earthquake happens.

The ERCs have traditionally functioned as small teams that work independently, and then gather to discuss their conclusions and approaches to create the earthquake drills. Each team is assigned the same task: create an earthquake response plan that outlines the safest actions that students should take during an earthquake, and then conduct at least one drill to test the response plan in action.

Question 2: What advantages might there be for teams to do the same work independently and then compare their different findings and plans? What are some of the disadvantages?

Possible answers: With small teams working for the same goal, each team can take a different approach that fits the group’s experience, and in so doing they might come to a different conclusion or emphasize a different area of importance compared to other teams. When the teams compare their results at the end of the activity, the input from these different perspectives can make the final earthquake drill more comprehensive, effective, flexible, and complete.

Some disadvantages might be that small groups of people lack the number of people necessary to tackle the volume of work expected, or it may not have participants with sufficiently diverse skill sets.

The ERCs (the students) should now be broken into 3-4 teams. Each team will work independently, using information from lessons 7-10, to develop an earthquake response plan for their school. The first task will be to research whether or not the school or community already has an earthquake plan. Assign one team to investigate this possibility and summarize the findings to the other teams before beginning their own earthquake response plan activities.

The remaining teams, meanwhile, should be assigned to work independently to develop a comprehensive earthquake plan. This drill must be specifically developed for the school, and should take into account its geographical and geological location, structural and non-structural hazards, surrounding environment (nearby structures, trees, power lines, etc.), and resources available within the community. To do this, the teams must be allowed to inspect the classroom and school to identify all hazards present (within the classroom and along any foreseeable evacuation routes), if this has not already been done in previous lessons. The teams should then figure out all possible earthquake responses and walk them out, mark them on a map of the school, taking note of any hazards that might be present along the way such as loose pipes or electrical fixtures, furniture, or even points where the flow of students from other classrooms may cause some students to be trampled. Encourage the team to use their imaginations to foresee the greatest number of possible hazard scenarios, and to develop simple response solutions that reduce the risk associated with these scenarios as much as possible. Hazards, evacuation routes, and helpful supplies should all be color-coded and marked on the map using colored pencils.

There are some general procedures that everyone in every community should follow, and these should serve as the basic guiding principles of any earthquake emergency response plan:

1) Don’t panic
2) Move away from windows, heavy objects, shelves, etc.
3) Grab any nearby earthquake emergency kits and hold on to them
4) Don’t use any elevators
5) Evacuate the building in a single file whenever possible

Note! Your school or classroom may only have one possible or practical earthquake response, depending on your school’s location and hazards along the evacuation route. Alternatively, the most practical response for some students in some locations may be to shelter-in-place. The most important aspect of conducting and evaluating an effective earthquake response plan is to consider all possibilities, and then to instill in students the reasoning behind selecting the course of action that is most likely to ensure their survival.

Question 3: Why is it so important for the team to ‘walk out’ multiple escape routes, and identify hazards along the way for each route? Why shouldn’t they just identify one escape

route and fully develop it? What are some advantages and disadvantages of this approach? Are there earthquake response plans that do not involve evacuation; why or why not?

Possible Answers: Each team must 'walk out' all evacuation routes because oftentimes the students are so familiar with these routes in their day-to-day lives that they overlook the true hazards that can arise during earthquakes. For example, in many schools there are pipes with steam or hot water running overhead that the students hardly notice. During an earthquake, a broken steam pipe can render an evacuation route unusable. Walking the route and looking specifically for these hazards can be a very eye-opening activity. The routes should also be compared by how much time it takes to reach a safe, designated meeting point.

Teams should develop multiple routes in case an unexpected hazard or circumstance has rendered the selected route unusable. But even then, it is not advised to merely tell the students what the best route is and expect them to do it; this misses the entire point of planning. Students must understand <u>*why*</u> *a route is the preferred route, and what the alternatives are should the route be unusable. Having the students determine the best possible route, and provide the reasoning behind the selection of the best route, empowers the students through inclusion in the decision-making process and trains them to use their best judgment when evaluating emergency situations, simulated or real.*

Some advantages of this approach are that more possibilities are discussed and evaluated, students are empowered to make the decisions that may save their lives, and systematic vulnerabilities to earthquake hazards can be discovered, reduced or eliminated with little or no cost to the school. However, there are also some disadvantages to this approach. Developing, evaluating, and selecting among many possible routes can be time-consuming and confusing if the drills are not conducted regularly to train the students to make fast decisions; however, it is the only way to avoid advocating an unrealistic 'one size fits all' policy of earthquake response since circumstances vary so much from city to city and building to building.

Some earthquake responses, such as shelter-in-place, do not involve evacuation. These responses may be necessary for earthquakes that are so powerful or disruptive that walking or running is not possible, or for buildings that are strong enough to withstand an earthquake, but there may be many non-structural hazards along the evacuation route. This is the case in most schools in California where "Drop, Cover and Hold" is a common procedure. For this procedure, students take shelter underneath their desk or table and hold on to the leg of that desk or table, with the other hand on the back of their neck to protect it from debris. Students should be prepared to move with the table or the object as necessary during the emergency. If this is a necessary strategy for a classroom, it should be practiced multiple times during the earthquake drill Tabletop Experiment below.

For shelter-in-place scenarios, the teams should critically evaluate any shelter-in-place resources (such as tables) as to whether such resources can realistically provide shelter from structural, non-structural, and secondary hazards. If the resources are not sufficient, it may be worth examining whether the appropriate resources can be put in place before an earthquake *strikes. For example, a number of small, flimsy tables might be exchanged for sturdy, stable, and larger tables that are being used elsewhere in the school (for no extra cost) that can shelter all students.*

After the ERCs have 'walked out' all of their possible escape routes and surveyed the school, ask the ERCs to consider the possibility that a student, group of students, or an adult have become trapped underneath debris (structural or non-structural) during an earthquake (if they have not done so already).

Question 4: What actions do the ERCs suggest to prepare for the possibility that some people may become trapped underneath debris during an earthquake?

Possible Answers: One possible answer is that a small survival tube may help victims of an earthquake trapped in a building. The tube could have a whistle, sterile water packet and a chemical light stick and a mask. The whistle can make sounds much louder than a voice without placing strain on the throat, and can also make noise while the trapped person conserves air in a confined place. The tube should be small so that students can carry it in their school bags or attach it under their desks or large tables so that they are quickly within reach.

One of the most important questions to consider is whether or not students should help an injured or trapped person during or immediately following an earthquake. This is a difficult question to answer since there can be so many different circumstances and levels of danger that an injured person may be facing. The first task should be to call for help, or to send a nearby person to find help while one person stays to comfort the injured person. If the injured person is in immediate danger and there are no other emergency personnel around, only then should a decision be made to move or attempt to provide care for an injured person. ERCs may want to consider providing additional training to students on emergency first aid techniques from qualified personnel if emergency response workers are not expected to be nearby if an earthquake occurs.

Finally, the teams should now discuss and compile all results from conducting their earthquake response assessment, so that the earthquake response plan can be developed and finalized. The teams should take turns outlining each possible response, marking the path of that response on a master earthquake response map and identifying all hazards, exits, and useful resources that may exist along the route of the plan. All response plans should conclude by identifying and planning to meet at an unambiguous designated meeting point outside the school. If certain resources are necessary or helpful for coordinating a response (i.e., whistles for emergency rescue, or medical supplies for small wounds sustained during an earthquake), have the teams produce a list of these resources as part of their earthquake response plan. If the school already has an earthquake response plan, have the students compare their independent assessment with the school's plan.

After the ERCs have compiled and finalized their emergency response plan, the plan is presented to the school administrator. The school administrator decides to put together emergency safety kits to place around the school. The school administrator asks the ERCs for help to gather materials for these kits.

Question 5: What are some of the items that should be placed in a family or community emergency safety kit? Where should the safety kits be placed?

Possible Answers: Immediate human needs are for food, water, and shelter. Any kit should include (at minimum) water, water purification tablets, canned or dried food (or any food that does not require a refrigerator), and some emergency blankets. Other very helpful needs are for information, lighting, and medical supplies. If possible, the kit should also include a battery-powered radio, flashlight, extra batteries, cash, a first aid kit, and family or class photos that can be used to identify or convey vital information about missing family or community members. Students or community members with special medical needs (such as vital medications) should take it upon themselves to ensure that their medical needs can be met with the items in the safety kit. Kits should be checked periodically to ensure the freshness and quantity of supplies.

The kits should be in easy-to-find locations that are at safe distances from structural and non-structural hazards. These should be locations that are also unlikely to be covered with rubble or debris should a strong earthquake occur.

Note! Remind the students that most disaster response organizations recommend that plans are made to provide complete care (i.e., food, water, clothing, and medical supplies) for a minimum of 72 hours following a disaster. Have them discuss whether this minimum amount of time is sufficient for the location of their school/community, given the accessibility of major forms of transportation, local climate, and availability of critical natural resources of the area such as fresh water. Let the students know that it may be constructive to petition the school to provide these resources for all students. Plan to eventually have the students present the results of their assessment, including the earthquake response plan and any critical resources or supplies necessary to carry out their plan, to local community safety personnel (i.e., fire, police, or other city or school officials) to receive feedback and guidance as to the appropriate people to contact and the appropriate steps to take after students have safely responded to the earthquake.

Tabletop Experiment: Earthquake Drill

Now that the earthquake assessment plan has been developed, the students are going to evaluate their plan by conducting at least one earthquake drill. There are two main reasons why drills are important. The first is that a planned response to an earthquake never quite matches an actual response. If any point of the plan was unclear to some students, then critical time may be lost during an earthquake emergency as students figure out what to do. Conducting drills should expose these problems and allow ERCs to correct them. The second is that certain critical brain functions do not function well during emergency situations. If an activity has been conducted numerous times before an emergency occurs (such as running down a hallway or escape ladder), then the brain is more likely to initiate that series of actions automatically under conditions of reduced brain capability. This helps to prevent paralysis due to overwhelming fear.

Note! The drill may arouse feelings of fear or anxiety for some students. Emphasize to students that these feelings are normal and healthy, but that learning how to avoid injury will increase their chances of survival. Be aware that inappropriate optimism ("It can't happen to me") is just as unrealistic as extreme fear and anxiety.

The educator is responsible for constructing the scenarios of the drill. Multiple scenarios are the best means of evaluating the effectiveness of the earthquake response plan, since the circumstances of an earthquake can vary. For example, one scenario may be for a slight tremor, while another scenario involves a very strong earthquake that makes walking or running nearly impossible. Smaller details of the scenarios should change from drill to drill as well: in one scenario, non-structural hazards (such as large bookcases) may impede the primary evacuation route, forcing the students to utilize secondary evacuation routes. The location where the drill scenario is initiated should change too: one drill may start in the classroom; another may start in a communal area such as a library, gymnasium, laboratory, and school bus or outdoors on a playground. The educator should walk out the evacuation path to come up with potential variations of the scenarios. During the drill, every effort should be made to simulate the actual sounds expected during an earthquake, including shaking windows, moving tables or chairs, and rattling glass, using actual tables, chairs, and windows located around the classroom.

Note! It may be helpful to videotape students during the drill. This may assist students with evaluating whether or not the decisions they made during the drill are appropriate.

Teachers must be ready to guide/help students during an earthquake. They must accept responsibility to do at least the following:

1) Maintain and carry a list of all students in their care; check the list at end of activities to quickly identify missing persons
2) Maintain and carry a first aid kit
3) Prepared to choose alternative evacuation routes (due to fire, for example)
4) Know how to safely turn off gas, water, and electricity in the areas surrounding their classroom.
5) Instruct students to evacuate after the shaking has stopped
6) Lead class to the designated assembly area
7) Secure everyone from the possibility of aftershocks
8) Give first aid if necessary
9) Do not re-enter the building unless instructed by an appropriate authority
10) If the teacher is injured, two students should be pre-selected to lead the others
11) Develop and implement a school plan, coordinated with the school administration, to reunite students with family members.

Note! Use telephones only for emergency purposes, and be prepared for situations where the telephone system is not functioning. In an emergency situation, it is very common for telephone systems to become inoperable because the systems and telephone lines have suffered earthquake damage, or the system becomes overwhelmed when everyone tries to use it at once, or both.

Post-Drill Evaluation

Students should *always* review what hazards can occur after the drill has ended (i.e., aftershocks, further building collapse, landslides, addressing medical injuries or people in shock, etc.). Just because the drill scenario has ended, and the students have secured themselves in a safe location, this does not mean that the exposure to hazards has ended. The students should know the steps to take after the drill has ended, such as administering first aid and gathering information about the emergency by turning on a radio or contacting an appropriate authority for further instructions.

After conducting each drill, the students should immediately evaluate the effectiveness of the choices made during the drill. Did the students make safe decisions, given the circumstances of the drill scenario? Are there some locations along the evacuation route where students can fall, trip, or collide with other students who are trying to exit? What can be done to minimize these types of accidents? If serious problems were uncovered with the earthquake response plan in the course of conducting the drill, discuss with the students how to alter the response plan appropriately.

The final decision should be to decide when the next earthquake drill will be conducted. The date should be agreed upon, but the time should not to maintain the conditions of surprise for those participating in the drill. Repeated drills with varying circumstances over an extended period of time will prepare students and educators to deal with unexpected emergencies quickly and safely.

Note! Consider the possibility to extend the drill to families and homes, and discuss the need for developing a family plan since students are likely to be separated from their family after an earthquake. Suggest that the students designate an out-of-area telephone contact and carry it at all times. Students should know how to turn off gas, water, electricity in their homes.

The earthquake response plan and color-coded maps produced by the students should be presented to school authorities and local government administrators. Students should be encouraged to discuss their findings with public figures responsible for public safety. Whenever possible, students should also have the opportunity to frame and display their final map so that other students in the school can know their work.

Lesson 12: Making a single-signature[1] book Supplementary information: 3-12

Codification activities are an opportunity for students to provide or invent a context that links curriculum concepts together. In the case of earthquake education, a codification activity should help students reinforce the concepts that make earthquake science, hazard awareness, and hazard prevention three aspects of a unified whole: earthquake safety. In this lesson, students use information from previous lessons to write stories about individuals or communities affected by an earthquake, and publish their stories in a single-signature book.

This lesson is adapted from an art/literacy project originally developed at the University of Washington's Pipeline Project (Stickler, 2000).

Allow 3 to 4 two-hour blocks for this activity.

Materials

Note! The following materials are sufficient to build one single-signature book. Multiply the materials below by the number of books that are to be made (one book per student). However, some of the items (i.e., glue sticks, scissors, sewing needles, and tape) can be shared amongst the students.

One sheet of colored paper (21.5 cm x 28 cm)
Six sheets of white paper (21.5 cm x 28 cm)
Sewing needles
1.5 yards of button thread
Paper clips
2 scraps of mat board (15 cm x 23 cm)
Colored plastic Scotch tape (4 cm width)
Scissors
Glue Sticks
Clear contact paper (optional)
Colored pencils, crayons, markers, papers, etc.
One copy of the writing outlines (attached at the end of this lesson)

Procedures

Day 1

1. Tell the students that each of them is going to write about an individual or a community affected by an earthquake. Explain to students they can invent the locations, characters, quotations, etc. for the story, but they are encouraged to include as much information from the previous lessons in their stories as possible. Distribute copies of the writing outlines (one per

[1] A single-signature book is a simple way of binding a book using a centuries-old bookbinding technique.

student) and ask them to fill out the top section. Students can work in groups together for this stage. Allow 10-15 minutes.

2. Now ask each student to do a story map using illustrations, words, or sentences. Explain to students that creating a story map may help them with writing the story. See Figure 1 for an example of a story map. To get them started ask students the following questions: Who should be in their story? Where does this story happen? What happens first? Students can choose to brainstorm ideas together or work individually. Encourage students to think about what kind of information from the previous lessons (science and hazards lessons) they would like to include in their stories and why. Allow 30 minutes or more for completing a story map.

3. Collect students' story maps at the end of classroom period.

Day 2

4. Return students' story maps along with a blank sheet of paper (or more). Tell them today they are going to finish their story maps (if they are not done already), and start writing the first draft of their stories (on the blank sheets). Encourage students to refer to their story maps when writing their first draft if they need to. Otherwise, students should feel free to diverge from their story map to incorporate new information as they proceed to complete their first draft. Allow the rest of the classroom period for this activity.

5. Collect students' first drafts and story maps at the end of classroom period.

Day 3

Note! Before the beginning of the class, create a few bookmaking stations in the classroom where students will be making their books in groups of 4-5. At each station allow enough materials for each student to make a book. Each station should have at least one pair of scissors, one glue stick, a few Scotch tape rolls of different colors, mat boards (2 per student), a couple of sewing needles and sewing thread.

6. Explain to students they are going to make a single-signature book. Provide each student with six sheets of white paper. Tell them six sheets of white paper make a 24-page book. Give each student one sheet of colored paper (for the endpapers). You may want to let students choose the color of their endpapers. Instruct students to fold their six pages of paper in half cross-wise (Figure 2). They can use their sheet of colored paper on the outside. Explain to them the colored paper will become their endpapers.

7. Instruct students to thread a needle with about 1.5 yards of button thread. Tell them they do not need to tie a knot, but they should even out the threads so they have two equal strands. Students may want to secure their folded pages by putting two paper clips on opposite sides as shown in Figure 3. Now ask students to mark four evenly spaced dots on the outside fold of their signature. These dots will serve as guides for sewing. Beginning at one of the dots at either end

of the signature, students should be instructed to poke the needle down through the top of the paper, and then come up at the next dot. They should then sew down through the following dot and come back up at the last dot (Figure 4). Students should now bring their thread ends together and tie a double knot in the middle of the fold of the signature. They can then cut out the ends, leaving enough thread so that the knot will not come untied.

6. Now is time for picking up covers. For their book, students will need two pieces of 15x23 cm mat board. Instruct students to cut a 28 cm piece of Scotch tape and place the tape sticky-side up on a flat surface. They should then lay their front and back covers down as shown in Figure 5, leaving at least 1 cm of space between the covers. They should then fold then ends of the tape over the top and bottom edges of the covers.

7. Now students should be instructed to use the glue stick to glue the first piece of paper to the inside front cover of their book. To do this, it is recommended that students close the book and adjust the fit of the back piece of paper, then open the book and glue the back endpaper to the inside back cover (Figure 5).

Caution! If students glue both endpapers down without closing the book and fitting the back page, it may pull too tight and tear when they close it.

8. If time allows, return students' first drafts and story map so that they can finish them. At this stage students should not be entering their stories into their books. Students who have finished their draft can start working on writing an autobiography page. The autobiography can later be added to the end of their books in an "about the author" page, where they can place a photograph (or drawing) of themselves.

Note! You may choose to take an author picture of each student for this activity, after making sure you have written approval from their parents or appropriate authorities.

9. Collect students' writings and books at the end of classroom period.

Day 4

Note! Before the beginning of the class, create a few art stations where students will be illustrating their stories and decorating their books. Each station should have colored pencils, crayons, markers, colored papers, and a pair of scissors.

10. Return students' writings, drawings, and books. Explain to the students that they are going to enter the final version of their stories into their books, illustrate their stories, and decorate their book covers. Divide them into groups of 4-5 students and guide them to each station. Explain to all students to begin by entering their stories into their books, allowing room in each page for an illustration that accompanies the text. Students may choose to draw an empty box of different dimensions in each page where an illustration can be fit. Each illustration can be accompanied by 2-3 lines of story or more.

Note! Give students their photographs from Day 3 (or portrait drawings). Students can glue them to the last page of their book next to their autobiography. Explain to students they can set aside a title page and a dedication page at the beginning of their books. The title page may include the title of the work, the author's name, and the copy right date. Help students cover their final product with clear contact paper for protection (optional).

11. Congratulate students for their published books. If time allows, students can take turns reading their stories to one another. Students will get to keep their books. You may choose to make photocopies of the pages of their books for later assessment of each student's learning throughout this curriculum.

Note! It is strongly recommended to dedicate a day to celebrate students' accomplishments, during which they receive a certificate for successful completion of all lessons and are recognized as published authors. Students can present their stories to their families, along with teachers and school administrators on the celebration date. In some schools, students may be allowed to place their books in the school's library where they can be read and appreciated by others.

Useful Internet Resources

The University of Washington's Pipeline Project: http://www.washington.edu/uwired/pipeline/

Teachers & Writers Collaborative:
http://twc.org/

References

Beven, R.Q., Crowder, J.N., Dodds, J.E., Vance, L., Marran, J.F., Morse, R.H., Sharp, W.L., Sproull, J.D., 1995, Seismic Sleuths-Earthquakes: A teacher's package for grade 7-12 (second edition), American Geophysical Union and Federal Emergency Management Agency, FEMA 253, 364 p.

Stickler, C., 2000, Making a single-signature book – Just like I did at Northwest Bookfest, prepared for 2000 Northwest Bookfest, Seattle, Washington.

Writing Outlines **Name: _____________**

This handout is adapted from Beven et al. (1995).

1. Enter in the story information below:

Date and time of the earthquake (real or hypothetical):________________________
Location: ___________________
Estimate strength and impact:
Richter magnitude: _________________
Maximum Mercalli intensity if known: ________________
Deaths: ________________
Property damage: ________________
Date of last earthquake in this region: _________________

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2. Now use the above information to draw a story map here:

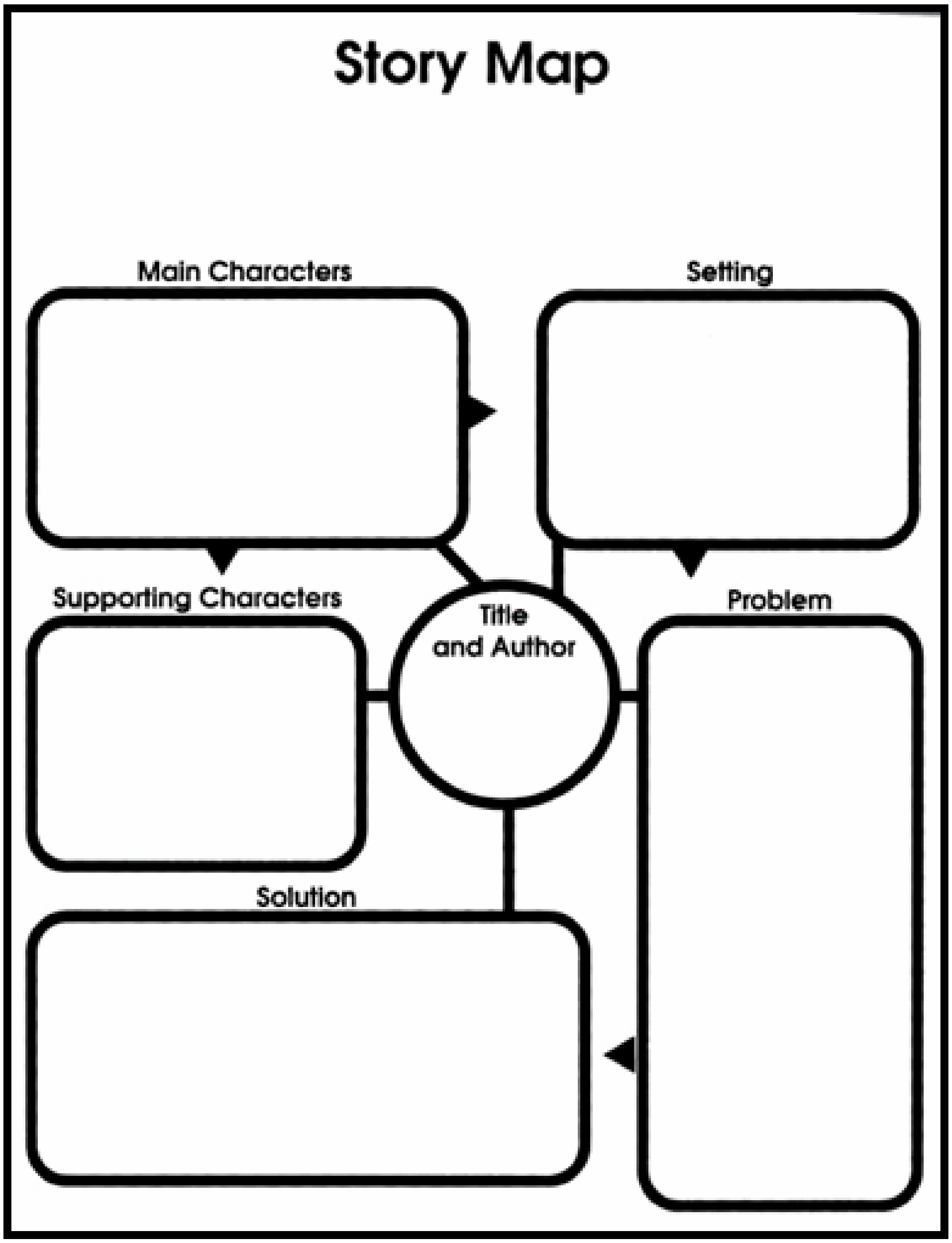

Figure 1. Example of a story map

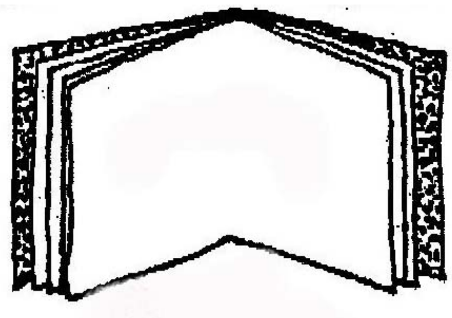

Figure 2

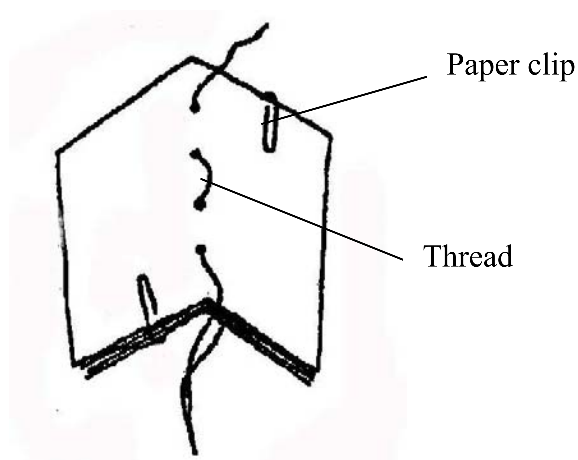

Figure 3

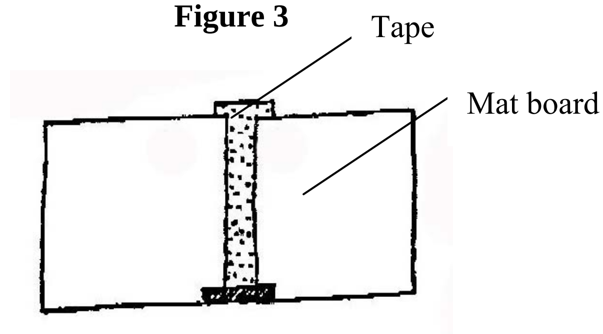

Figure 4

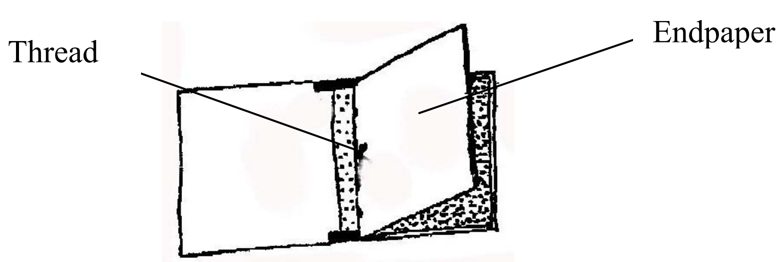

Figure 5