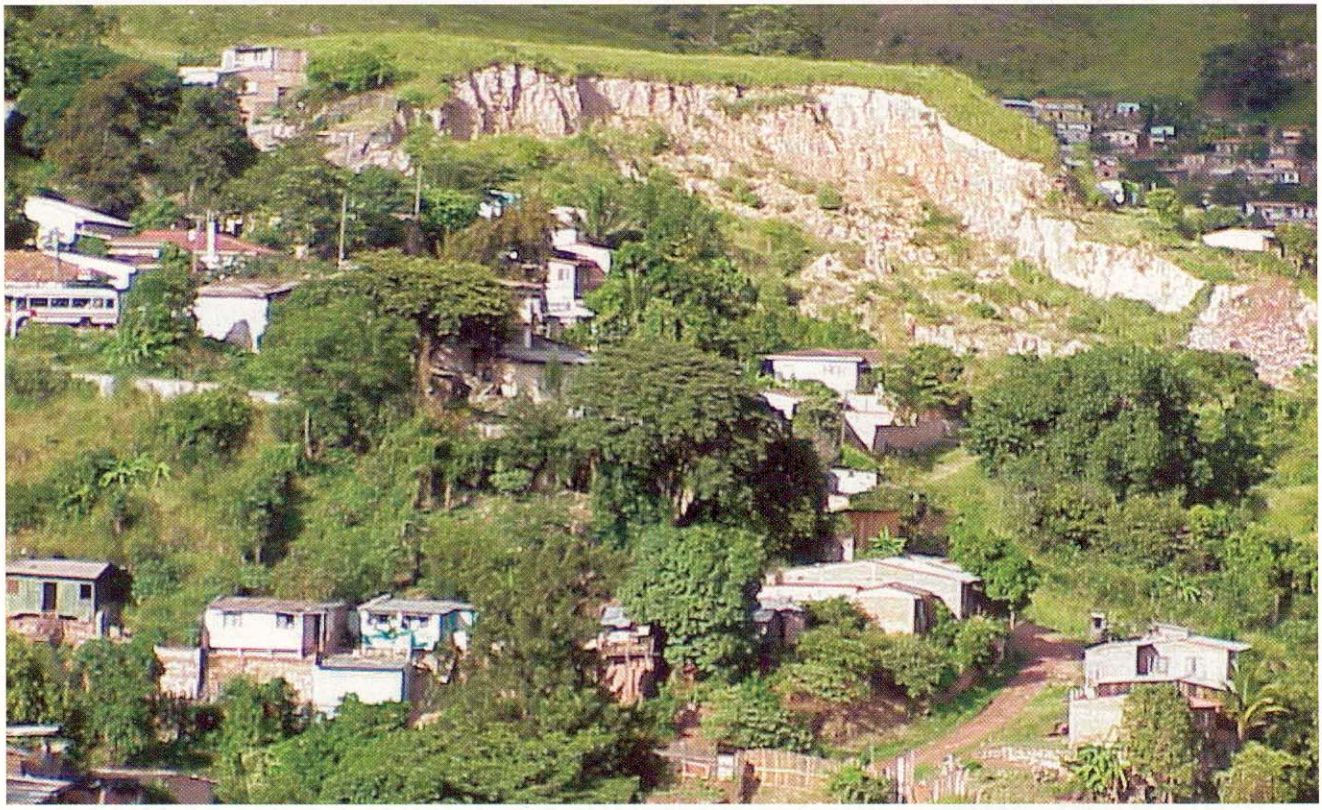
Rapid Reconnaissance of Major Landslides

By Richard S. Olsen, Ph.D., P.E.



A landslide in El Reparto hillside of Tegucigalpa, Honduras.

Introduction

Field assessment of large landslides should be performed as soon as possible after they occur because critical clues will disappear with weathering, further failures, and as consequences of recovery efforts. The landslide triggering mechanism must be quickly identified to assess immediate safety and for the design of landslide mitigation measures. Landslides can be compared to the personalities of people; each one is unique and complex and should not be quickly judged on face value.

Segmental Behavior

Large landslides do not move as monolithic blocks; they move in segments, experience time lag, and exhibit complex deformation behavior. Careful examination of a large landslide will reveal evidence of this segmental behavior. When a large landslide occurs, it provides a slope stability factor-of-safety equal to one for each segment failure; you only have to determine why. You must be able to explain how each segment of a landslide got to its final position.

Triggering Events

Large landslides are normally triggered as a result of smaller, localized events, such as small landslides at the toe of the hillside. Cultural changes to a hillside within developed areas (especially marginally-developed areas) can act as the triggering event. Minor changes to a hillside such as streambed changes, changes to vegetation load (and type), broken lined drainage ditches, malfunctioning of underground water/sewer/drainage pipes, diverted surface runoff, cleaning/repairs to infrastructure, and ignoring recommendations, can influence local stability. A hillside will react to events such as a cut in the slope, by mobilizing additional available

strength with movement of the slope (i.e., strain). This slope movement can appear as a minor slump if the soil stiffness (shear modulus) is low, such as for soft clay. Small landslides or slumping can quickly lead to multiple segmented failures, which may eventually involve the entire hillside. For example, an initial small cut is made into a hillside, possibly triggering a localized landslide. This landslide then causes blocking of internal geologic drainage paths. The surface drainage changes, and ultimately, a large landslide occurs.

Non-circular Landslides

A non-circular landslide having both a central and passive block generally has limited potential for movement. During landslide movement, the soil must change from the central slip surface direction to the passive slip surface direction (upward), which expends energy, and reduces movement potential, and results in a remolded soil zone. It is possible to have dramatic slope deformations, but only if the remolded zone is large and the remolded strength is low. Many landslides have a stair-step appearance where the soil mass traveled downward as different segments. In this case, the initial movement of the non-circular slide can generate a large remolded soil zone inside the toe of the slide. This zone of remolded soil then triggers another segment to start sliding inside the initial landslide mass.

Office-Based Analysis

Field observations must drive office-based landslide analysis. No amount of computer analysis, neither Limit Equilibrium Method nor Finite Element Method, can replace field observational information. Large landslides may be approximately evaluated using conventional techniques, but foreknowledge of the triggering mechanism is absolutely required. Try to perform stability evaluations for each stage of a landslide: triggering, initial movement, after soil remolding (if applicable), stoppage of movement, and post-remediation.

Performing Good Field Observations

The best time to capture critical details about a landslide is "immediately" after the failure. Seemingly minor details can lead to big discoveries and provide the only clues about the landslide triggering mechanism. This type of fieldwork is not just about collecting data. It's about looking for answers and collecting support data. If you don't know what you are looking for, you will not find it. You must know what to look for, what is normal, what is inconsequential, and what could be a trigger event. All unknowns must be committed to paper—no "mental notes." Prior experience with planning techniques,

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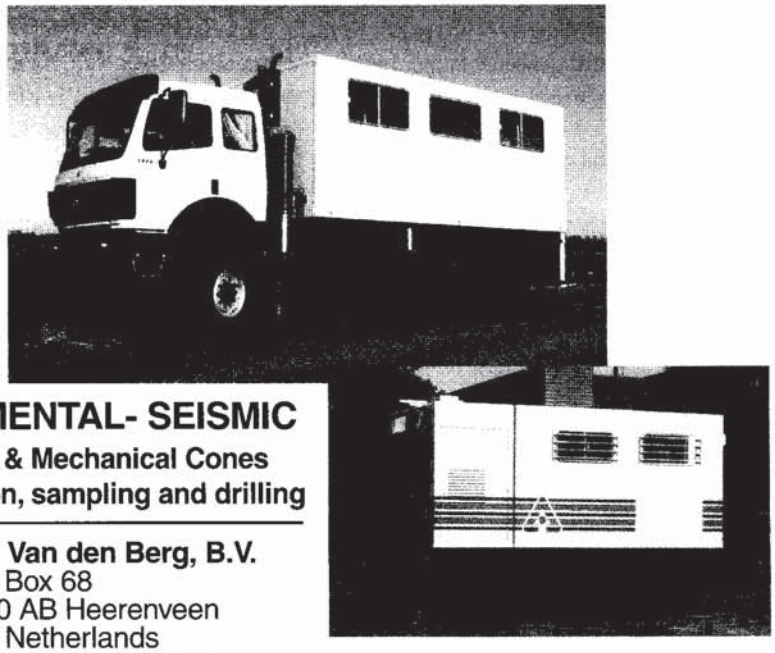

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field equipment, hardware, software, basic geotechnical failure behaviors, and field procedures is essential. You must identify immediate threats and future investigation protocol.

Observe the landslide from all sides and inside the landslide area, if possible, to look for reactions and behavior. Focusing your attention on tension cracks at the top of a hillside will not lead you to the landslide triggering mechanism, because these cracks are normally the last part of a total slip surface to move. Exposed landslide segments inside a landslide mass should also be examined for sandy layers, because elevated pore pressures are always important. And finally, identify the differences between landslide and unaffected adjacent land.

The San Vicente landslide (40km east of San Salvador on the Pan American Highway) was triggered by the January 2001 El Salvador Earthquake and covered the highway with 20 meters of debris.

Photographs

Be leery of landslide photographs taken by others—for example, sent by E-mail. The supplied photos can be of obvious observations, at poor orientations, and missing important details. If the photographer does not know what to look for, he probably won't photograph it. Try not to make important decisions before visiting the site based on those photographs.

Taking good technical photographs that also can tell a story is an acquired skill. There is no such thing as too many photos. Use a digital camera at a high resolution (at least 3 megapixel) and don't use digital zoom. After leaving the field, you need to "weed" through the digital photographs and move those that do not convey the best information into a subdirectory entitled "less valued photos" and poor images into a subdirectory entitled "poor photos." In that way, you won't worry about throwing out potentially needed photos.

Sequence photographs are important to document time changes at the landslide. These photographs can be made into animated images for web sites, presentations, and CD-based reports. Sequence photographs should be taken every time the site is visited. Use the same camera with the maximum wide-angle setting. You must record the locations where you stand for each sequence series photo and the precise direction of the camera.

Helicopters

Helicopters are important to capture lateral oblique images of large landslides that cannot be achieved from a ground perspective. Lateral oblique aerial photographs must show the landslide surface profile together with orientation and shape of the segments inside the landslide. You should be able to use a combination of lateral oblique and vertically-oriented aerial photographs to identify landslide segments and then sequentially piece the landslide back together. Work with the helicopter pilot during a preflight meeting to plan flight paths toward the landslide at different elevations and orientations to get good photographs. Good pictures are not accidents!

Measurements

It's often a good idea to measure strengths of freshly exposed clay soil surfaces directly after a landslide. Be prepared to cut away any recently desiccated clay. You must have experience properly performing torvane and field vane measurements to ensure valid data. Consider using high accuracy survey measurements (i.e., Real-Time Kinematic (RTK) 2-cm GPS (Global Positioning System) during the first visit to capture the current landslide shape before any additional future slope movements. A standard WAAS (Wide Area Augmentation System) GPS (at 2-meter accuracy) is sufficient for establishing locations for photographs and note taking. Use a time stamp to index the photographs to paper, personal computer (PC)/personal digital assistant (PDA), field notes, and finally to a GPS waypoint location. Synchronize your wristwatch, camera clock, and PC/PDA clock to the GPS time before going into the field. Date/time stamp photograph images. Drop the field data into a GIS (geographic information system) (or other mapping software) within a half-day of the fieldwork.

Interviews

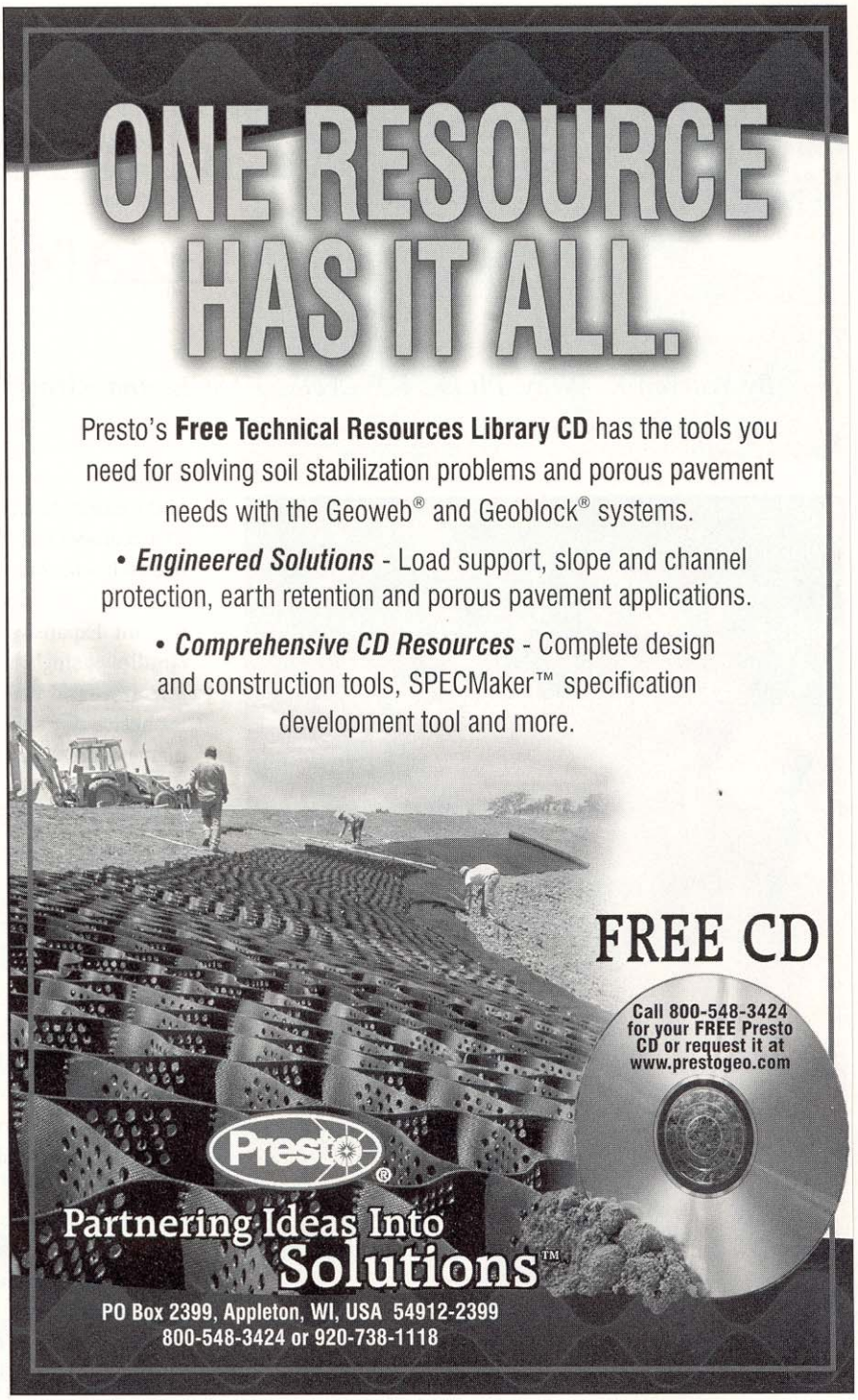
Interviewing people always provides good information. Locate people who experienced or witnessed the landslide,

or who saw the aftermath of the landslide. Don't ask questions that make it appear you are trying to establish blame. Work on what they *saw* rather than what they *think*. However, let them talk about "other" observations which they might not think are germane, such as water or power outage before the landslide, initial movement characteristics, pre-slide cultural activities in the community/hillside, recent construction, vegetation changes, recent changes in surface runoff character, recent erosion activity, recent construction/repairs, structural/foundation problems (e.g., stuck doors), extremely old ground failure information, etc. In foreign countries, teach landslide fundamentals to the person doing the language translation, and then break the questions into small "sound bites." Remember that many landslides are triggered at the pre-slide hillside toe, and interviews might provide the only clues.

Working As An Expert

The task of an expert is to convince officials/client of needed actions. Don't contribute to a secondary failure by not being able to convince officials of your assessment and recommendations. Don't be surprised if you are the second or third expert to be consulted. The official/client may not feel good about previous interpretations. You must be able to quickly generate a graphical story of complex observations for one-on-one meetings, client briefings, and potential media briefings (cleared through appropriate officials). Make sure that your graphics are understandable—even by your grandmother.

Talk only about issues that are within your expertise and those you fully understand. Be careful about assuming what you think you understand. Consult with others, or defer answering about issues that you don't fully understand and can't control. Make sure you understand the questions and thoroughly think through the answers before responding. Be situationally aware as to how the listener will react to what they hear. Immediately understand who's in charge and who controls resources. Know when to talk, when to push, when to comment, and when to hide. Ultimately, being an expert requires convincing officials to accept and act upon difficult recommendations. ❍



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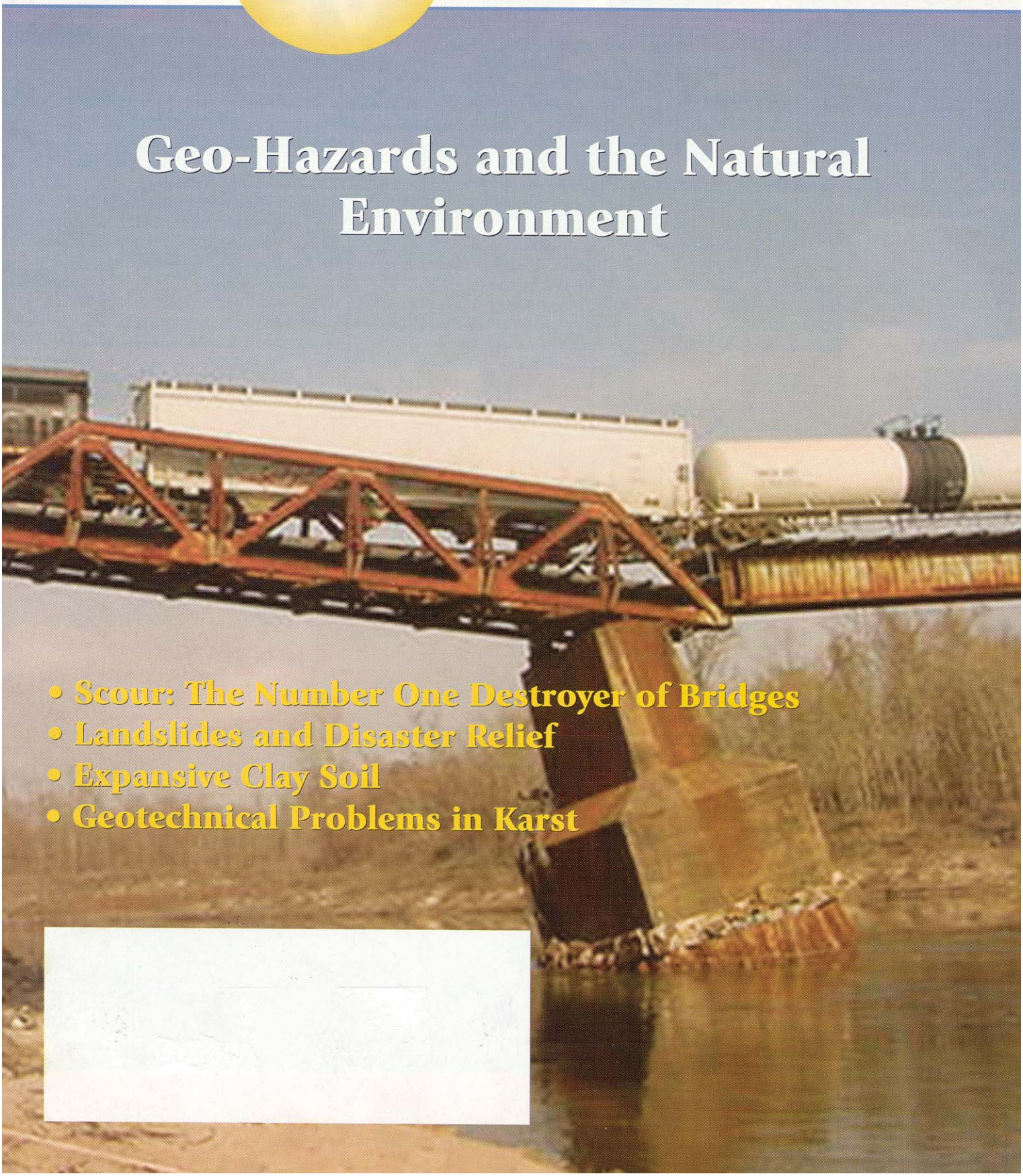

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