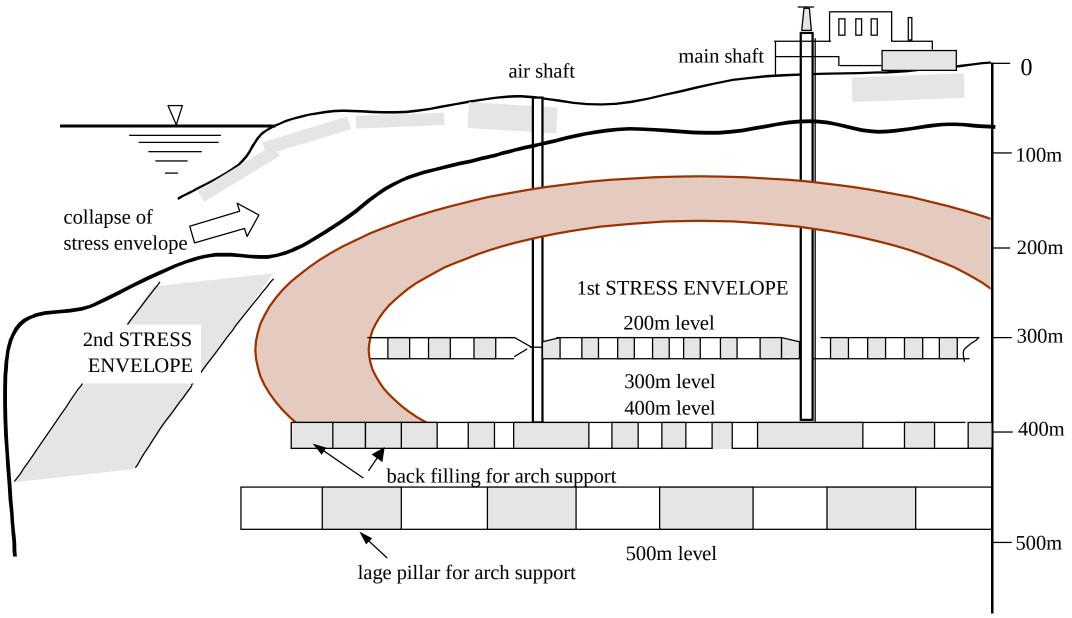
SERATA GEOMECHANICS CORPORATION

Automatic Stress/Property Measurement for Earthwork Optimization

CATEGORY 4 EARTHWORK APPLICATION EXAMPLES

— Serata Stress Technology (SST) Application Examples in General Earthwork —



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Serata Stress Technology (SST) Application Examples in General Earthwork

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Serata Stress Technology (SST), which was initially developed for the safe disposal of the nation's high-level nuclear waste, has been found immediately useful for earthwork in general. The general application has been made successfully in diversified areas of mining, tunnel, dam, slope, foundation, underground space and earthquake time-prediction in 10 different countries at various stages of development as summarized below.

1. MINING INDUSTRY

The potash and salt mines in U.S., Canada and EU were suffering extensive ground failure because of the basic weakness of the evaporate ground. Many mines, which were facing imminent abandonment of their total operations, have been saved miraculously by the use of SST. Essence of the application is summarized briefly as follows.

1) Aging Deterioration of Ground
   Upon excavation of ground, materials around the opening deteriorate by aging as illustrated in Fig. 4-1. Such deterioration takes place immediately as well as slowly taking many years dependent upon the basic nature of stress state and material properties of the ground. SST with Serata Probe enables us to measure and analyze the aging process automatically, simultaneously and quantitatively, so that the ground safety is digitally analyzed for the design optimization as illustrated in Fig. 4-2.

2) Multiple Room Entry
   Often, the aging effect is so rapid that roof caves in and floor heaves up before completing the required safety assured stress control design. In such a rapidly moving ground, narrow yield pillars are introduced between multiples of rooms to allow natural formation of a large protective stress envelope to establish a self-supporting mechanism immediately as shown by Fig. 4-3. Such design optimization had often achieved large amount of savings in major mining operation in US, Canada, EU, Australia and India. In all these cases, their initially narrow rooms, which were suffering intense ground failure, were systematically expanded often more than ten times of conventional size as summarized in Fig. 4-4.

3) Expansion of Scale
   The initial Technology development was made in mining by the small opening of 3m

x 6m in the 1960s to 1970s. The scale of excavation was gradually expanded to large production panels with its width approaching 1000 meters in the 1980s and 1990s as shown in Fig. 4-5. The scale is further expanded to the large global structures of many kilometers including an entire salt dome as shown by Figs. 4-6.

4) Application to Complex Mining Ground

The Technology was successfully applied to other mining including coal and metals in the manner identical to the salt and potash mining. As expected, no fundamental difference is found among them, demonstrating usefulness of SST regardless of type of ground and method of mining. Our proprietary (finite element) modeling program (GEO) is proven useful to simulate the ground behavior, which includes complexity of elasticity, visco-elasticity, visco-plasticity, brittleness and strength deterioration as a function of time. Further details are available upon request.

5) Recognition by NIOSH

National Institute for Occupational Safety and Health (NIOSH) is the nation's research center for mining studies in US. The Institute recognizes the importance of earth stress condition as explained by their publication (March 2001) "Focus on Ground Control: Horizontal Stress", strongly advocating the importance of stress measurement for mine design as illustrated by the upper sketch given in Fig. 4-7. Apparently, the sketch is a rough guesswork made only to give a warning without giving any solution. To get the digital solution with in-situ validation, you need to measure and control the actual stress condition as illustrated in the lower section of the figure, which is an actual case of Sifto mine in Goderich, Ontario, Canada. Further details on the successful case are given in Category 3.

2 EARTHWORK CONSTRUCTION INDUSTRY

SST is finding its way into the construction industry. No doubt, the digital optimization, which has been achieved in the mining application, is urgently needed for the industry. The current effort made for the SST introduction is summarized below.

1) Concrete High Dam

The concrete high dams all over the world are aging and in need for accurate digital monitoring on long-term safety of the structures. No existing method enables us to monitor in-situ condition of stress state and material properties inside the concrete body accurately and economically. More specifically, the conventional stress and property measurement methods always destroy the position in a test hole at each single measurement. This makes any continuous safety monitoring of stress/property in any dam virtually impossible. In contrast, SST enables us to carry out high accuracy measurements repeatedly by utilizing the same old test hole indefinitely, making automatic safety monitoring of high dam possible for the first time.

2) Tunnel Construction and Maintenance
The powerful analysis method developed for underground mining can also be readily applied to investigation and design as well as construction and maintenance of tunnel work. Optimization of the tunnel construction work may be achieved most effectively and economically by direct application of SST.

3) Slope and Foundation Work
By having direct monitoring of active condition (stress state and material properties) in slope and foundation, the structure is analyzed digitally as a function of time for long-term safety. Scheme of such SST application to a major slope is illustrated in Fig. 4-8.

4) American Standard of Testing Materials (ASTM)
It is a matter of time that SST becomes a new basic standard for the ground construction industry in U.S. as well as the rest of world. The laboratories of U.S. Bureau of Reclamation in Denver, Colorado are working for the introduction of SST to American Standard of Testing Materials (ASTM).

3. UNDERGROUND STORAGE OPERATION

Immediately following the successful saving of the salt and potash mines in US, Canada and EU, SST was successfully introduced to underground storage of oil, gas, raw materials and compressed air energy in US, Canada, Brazil and Germany. The major companies served by SST for their storage operations are given in Category 6 “Global Project Record and References”.

In a thick salt bed, a number of cylindrical caverns are created close together for liquid storage as shown by a plan view given in Fig. 4-9, in which cavern boundary failures are analyzed by matching between field measurements and model behavior. Many large scale oil storage cavern fields have been developed and utilized over 25 years successfully in a salt dome in Louisiana, USA, as shown in Fig. 4-10. The world first underground solution cavern designed for compressed Air Energy Storage (CAES) was successfully developed by SST and operated by working with EPRI (Electric Power Research Institute) in the McIntosh salt dome in Alabama.

For further information contact Shosei Serata at serata@serata.com or (510) 659-8630 / (510) 797-4228.

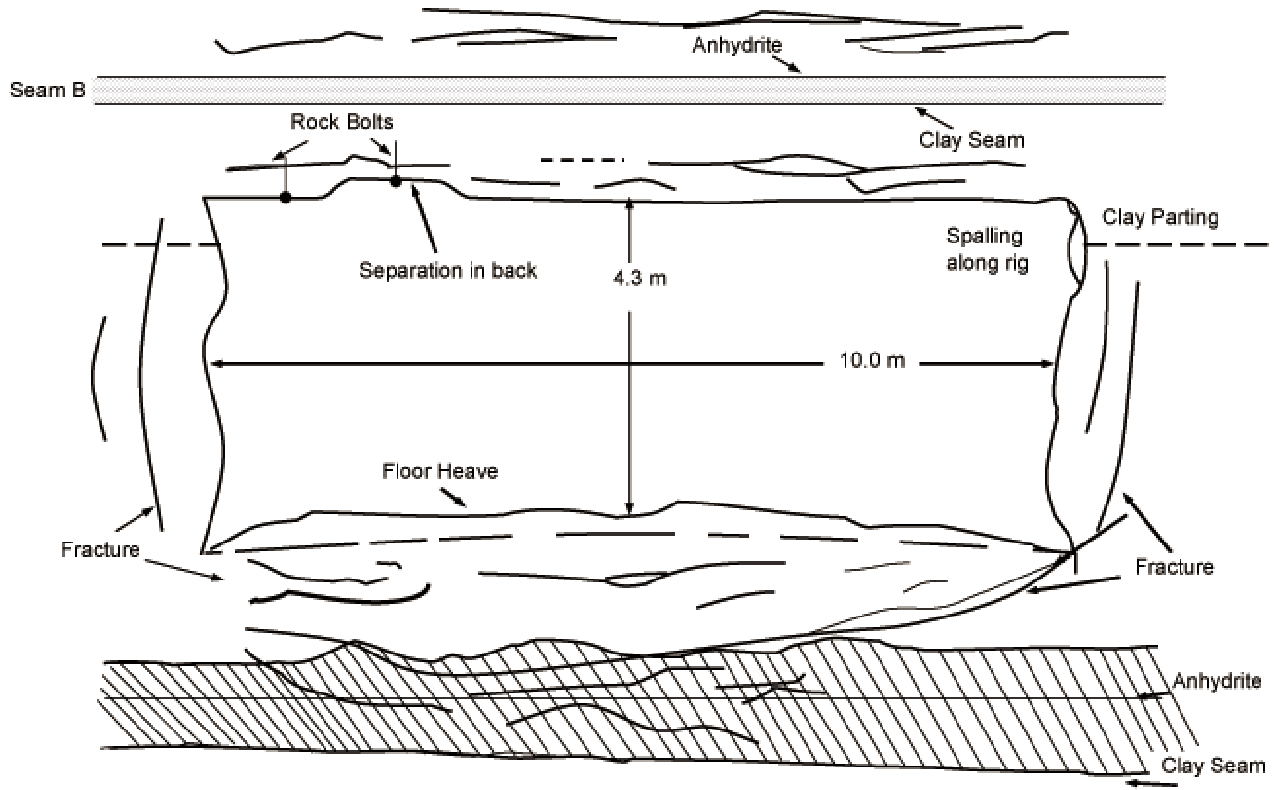
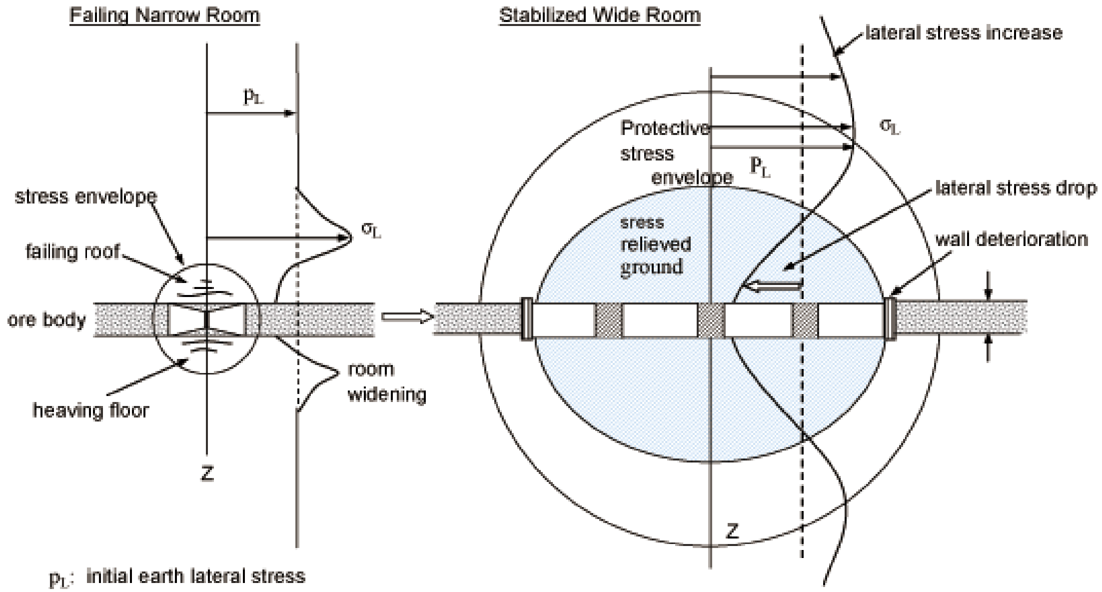


Fig. 4-1 Observation of creep failure around underground opening at WIPP nuclear waste repository site disclosing time-dependent stress and property changes continuously taking place around the opening.

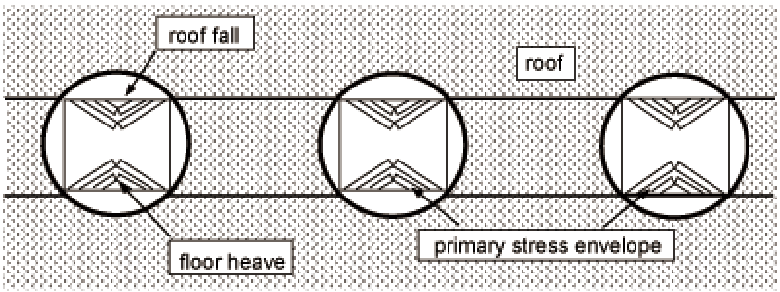


p_L: initial earth lateral stress

σ_L: lateral stress after excavation

Fig. 4-2 Mechanism of wide room method effectively utilizing stress envelope to stabilize failing potash and salt openings by introducing stress-relieved buffer zones above and below widened room

CONVENTIONAL ROOM & PILLAR ENTRY



STRESS CONTROL ENTRY

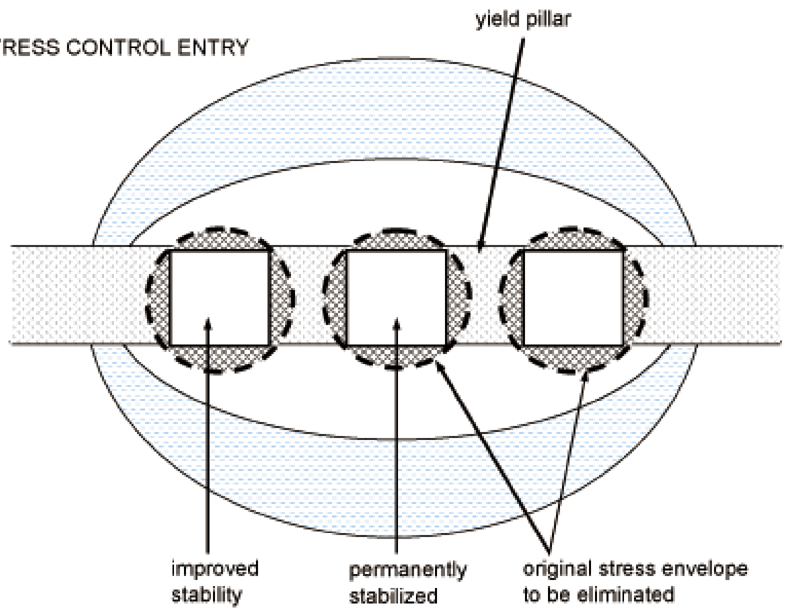


Fig. 4-3 Formation of permanently stable "second stress envelope" designed to stabilize failing mine openings by grouping them with narrow yielding pillars

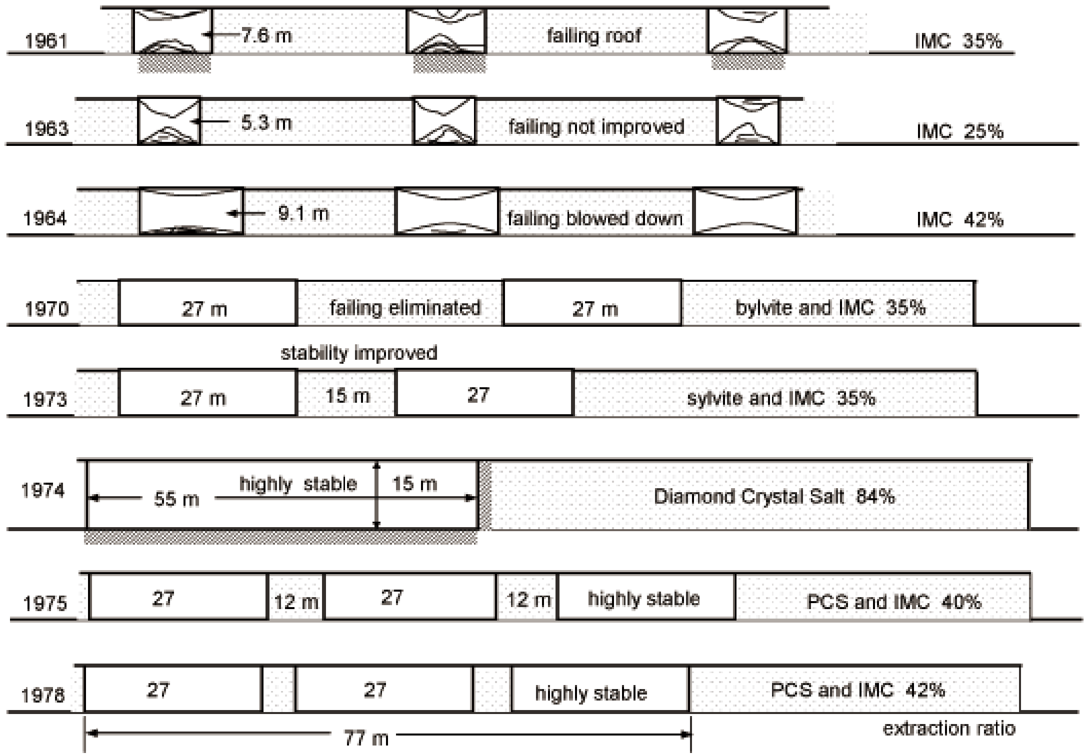


Fig. 4-4 Field demonstration of Serata Stress Technology (SST) successfully applied to deep potash mining in Saskatchewan, Canada. The 77m room-pillar span excavated in 1978 has been stabilized naturally without roof bolting, while 5.3m rooms excavated in 1963 continued failing even with saturated roof bolting, vividly demonstrating the power of SST

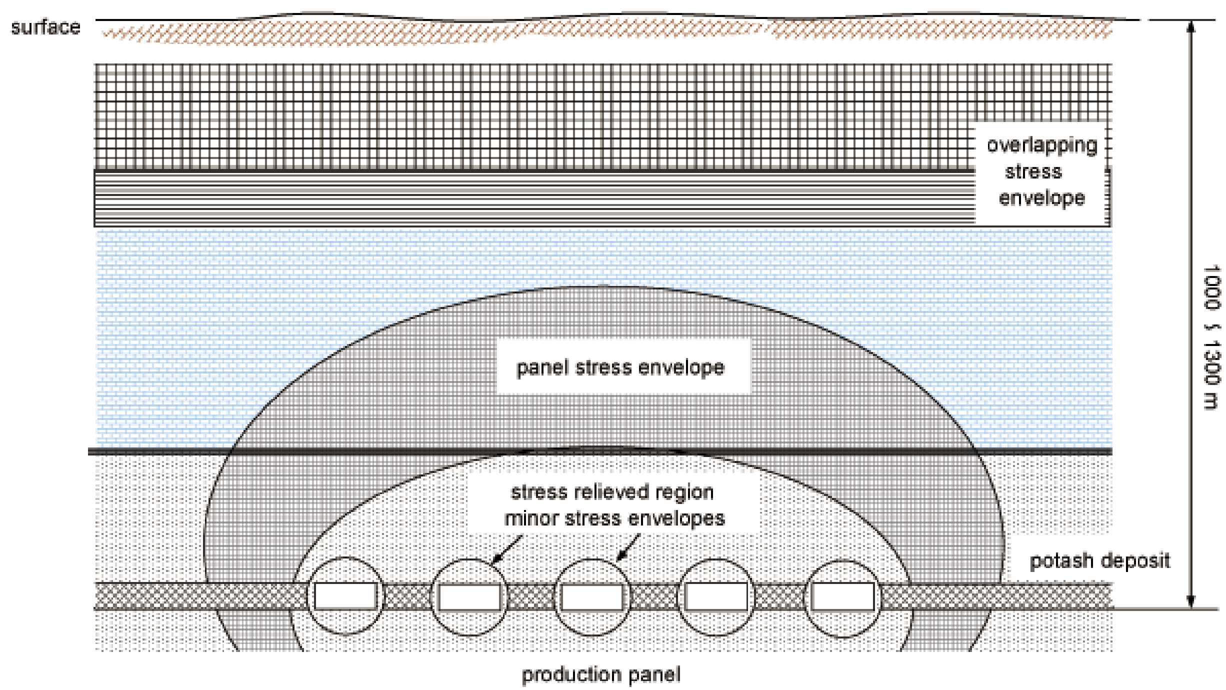


Fig. 4-5 Stress Control Method applied to stabilize deep underground openings

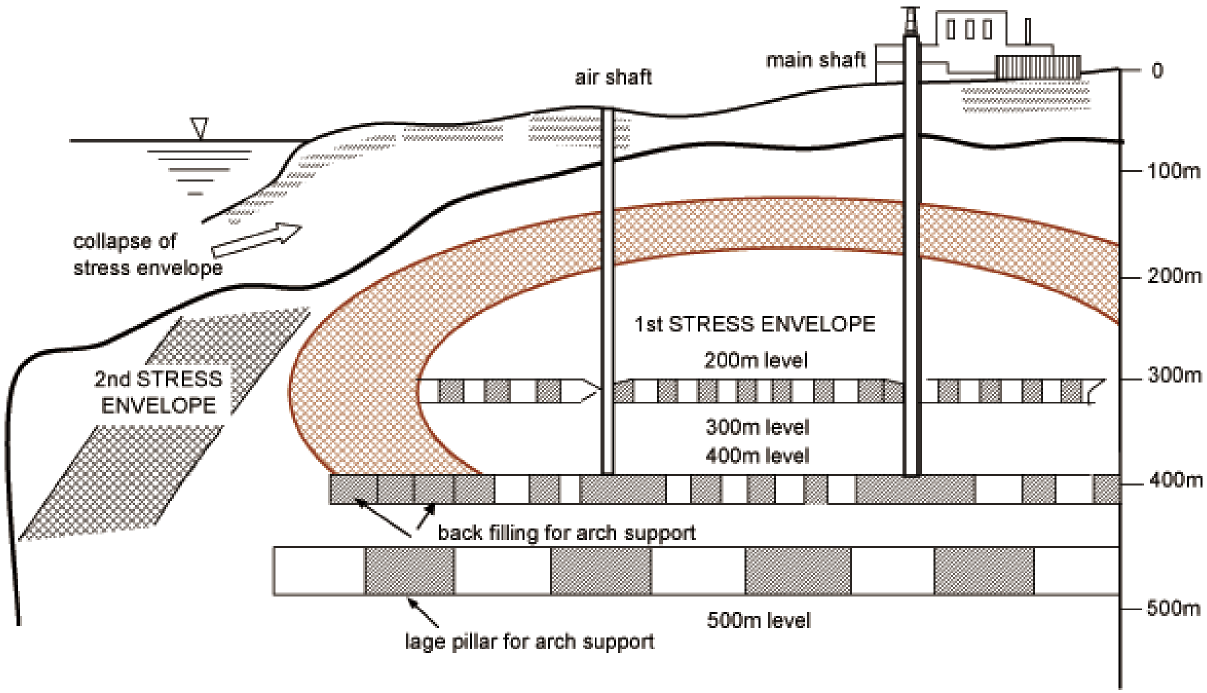
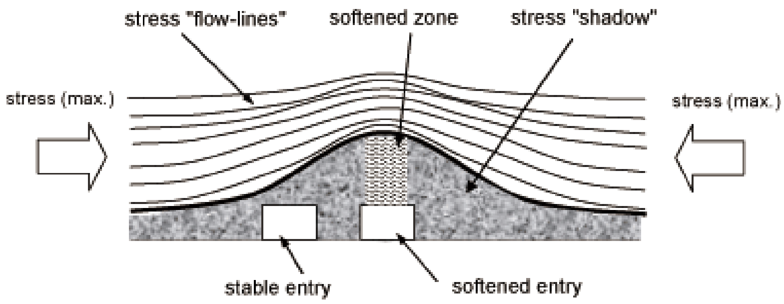


Fig. 4-6 Sudden subsidence increase over salt dome caused by undermining global stress envelope at 400m level, which was verified by the stress measurement. The entire salt dome was stabilized by reestablishing the global stress arch in Diamond Crystal Salt mine of Jefferson Island, Louisiana.

Generalized stress damages over mine opening by NIOSH



Failing ground of Sifto salt mine stabilized by SST

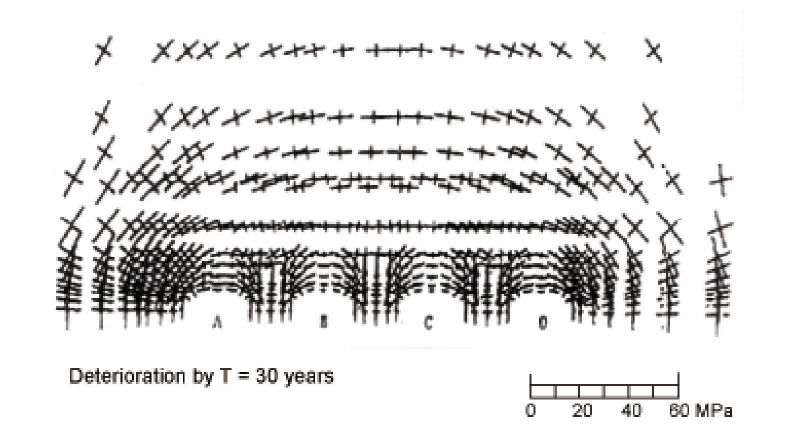


Fig. 4-7 NIOSH warning of stress problem with generalization of destructive stress conditions over mine opening (above) and SST stabilization by formation of protective stress envelope to relieve destructive stress from immediate roof area (below). SST permits accurate measurement of the stabilized stress condition

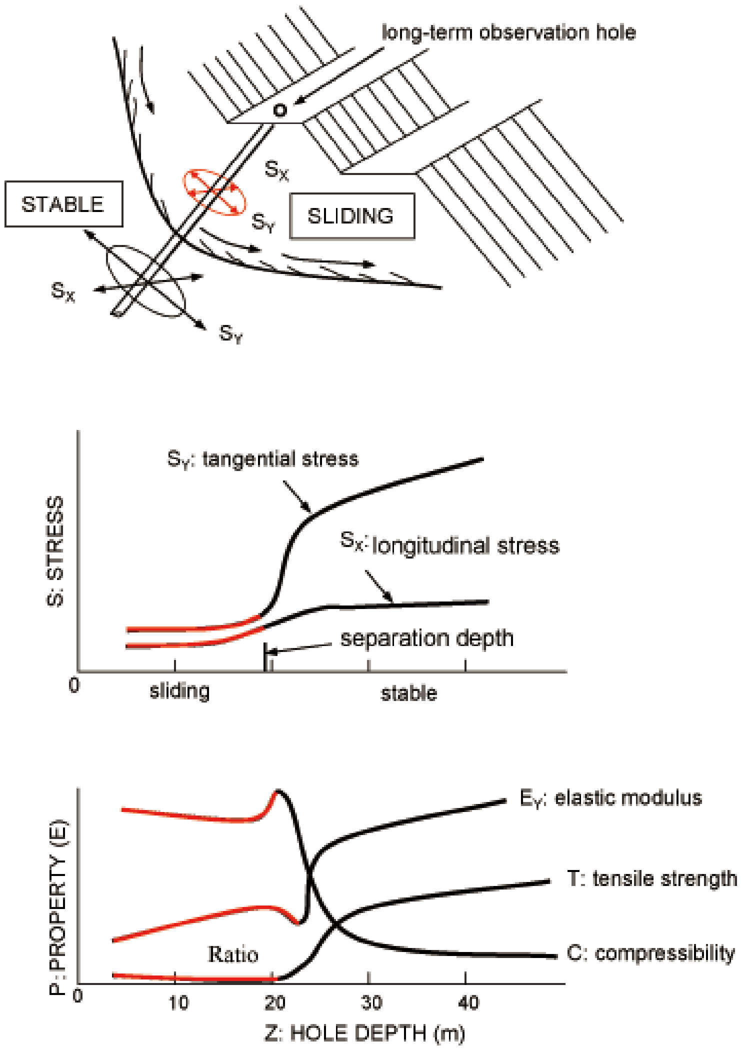


Fig. 4-8 Stress/Property measurement for detection of slope deterioration

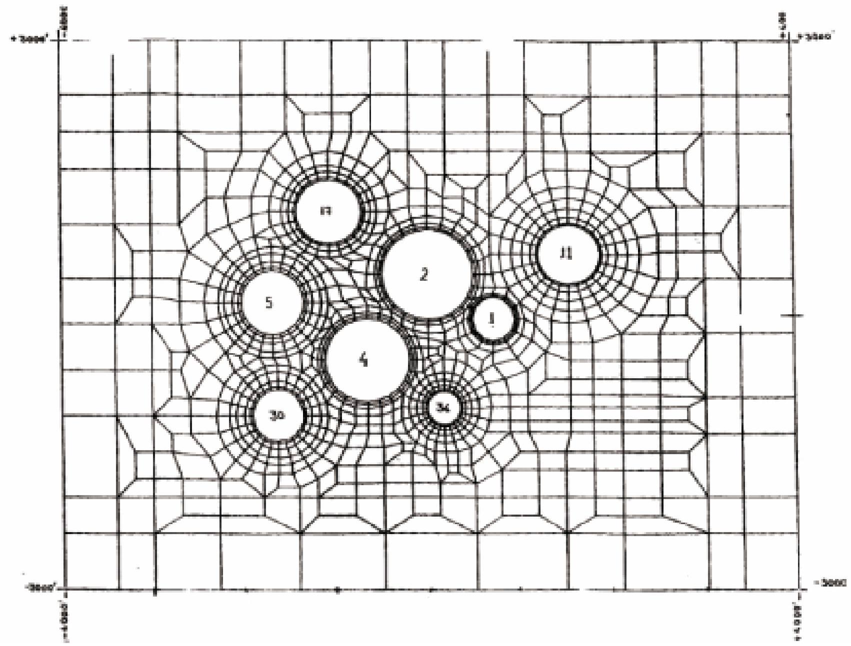


Fig. 4-9 Interaction of closely-spaced solution caverns developed in bedded salt formation in the Great Lakes area assures safety of long-term oil storage operations by regulating cavern pressures

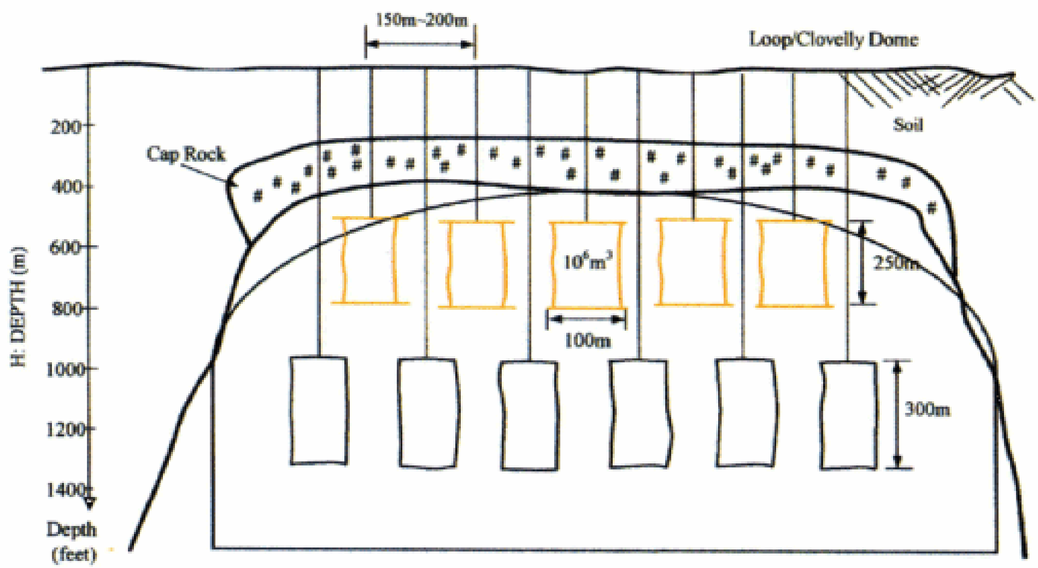


Fig. 4-10 Maximum utilization of salt dome space for underground oil storage cavern field developed by SST for Louisiana Offshore Oil Port (LOOP) at Clovelly Salt Dome, Louisiana