RISK-BASED DECISION SUPPORT FOR HOUSING DEVELOPMENT ON UNDERMINED LAND

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Extended Abstract

A simulation model was developed to provide risk-based decision support to the Three Sisters Mountain Village (TSMV) land development. This land development is located in the resort town of Canmore, Alberta, just east of Banff National Park and is situated above the site of a former coal mine. In the time period since mining operations ceased, the TSMV site has been susceptible to ground subsidence events caused by the collapse of underground voids from the mining. Golder was commissioned to act as the undermining engineer for the developer.

Included in Golder's commitment were recommendations on risk mitigation techniques including avoidance, structural reinforcement and ground treatment. One of the methods used by Golder for supporting risk mitigation was the development of a quantitative (probabilistic) simulation model. The simulation model was used by Golder to predict the probability of consequences caused by subsidence events over a 50 year timeframe from the date of construction. The mathematical model on which the simulation was based used standard geotechnical equations from the mining industry and empirical research relating subsidence events to building damage, and in turn, repair cost. The quantification of uncertainties in both subsidence (geotechnical risk) and repair cost (financial risk) was then added to the model.

A combination of classical and subjective probability approaches was utilized for the uncertainty quantification. Subjective probability was used to quantify incomplete knowledge of measurable geotechnical quantities. In particular, triangular were used which bounded these quantities in terms of maximum, minimum and most likely estimates. The depth of maximum available subsidence was fit to empirical data from the technical literature using the Kolmogorov-Smirnov method. The optimum distribution which also made physically sense was a lognormal distribution. This is an example of a classical frequency approach to uncertain quantification, based on statistics. Time evolution of subsidence events was modelled from a heuristic approach

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using a binomial distribution which took into account no (most likely), single and multiple (least likely) subsidence events which could occur over the 50 year timeframe of interest. This binomial model accounted for the exponential decrease in frequency of subsidence events occurring over time.

Uncertainty was incorporated into a previously published consequence model which linked the degree of subsidence to cost of repair. The original deterministic model mapped empirical measurements of subsidence in terms of tilt, angular distortion (related to the subsidence profile) of the ground, and the direction of horizontal ground strain to discrete ranges of relative repair cost on a scale from 0 to 5. Here 0 represents no repair cost and 5 represents 100% repair cost which corresponds to the cost of replacing a house. By introducing probability in the form of beta distributions, the possible variation within each range is taken into account, including a tail portion, which extends out of the upper bound of the relative repair cost range. For example, even with a 100% repair cost, the actual repair cost could exceed the original repair cost once engineers, surveyors and lawyers are involved in the reconstruction process hence pushing up the final price.

The simulation model was implemented using the GoldSim modelling environment. GoldSim is objected-oriented and highly graphical. It explicitly shows the mathematical relations between system variables using influence diagrams. It also comes with a built-in suite of probability functions. The output probability distributions for both geotechnical and financial consequences are computed using Monte Carlo algorithm with built-in variance reduction techniques.

This presentation describes a portion of the risk model which was applied to a $70M subdivision comprising approximately 100 houses. We show how the risk model was used in a practical way to assist Golder in making the optimal set of recommendations as to whether (or not) to invest in structural reinforcement on a house by house basis.

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Risk-Based Decision Support for Housing Development on Undermined Land

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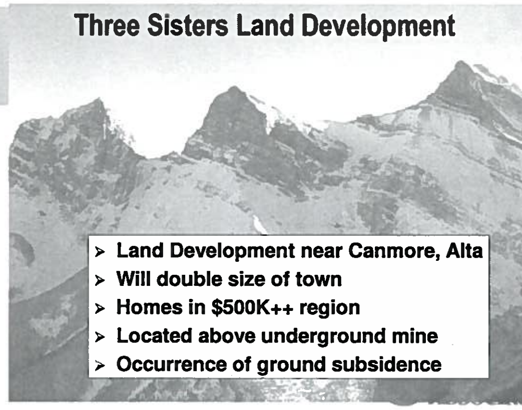
Three Sisters Land Development



- Land Development near Canmore, Alta
- Will double size of town
- Homes in $500K++ region
- Located above underground mine
- Occurrence of ground subsidence

Building Houses on Undermined Land


During Mining


Today

Risk Mitigation Options:
✓Ground Mitigation
✓Structural Mitigation

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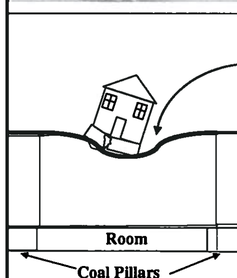
Mining Subsidence 101



- Subsidence events uncertain
- Also magnitudes uncertain
- Causes depressions in ground
- Serious foundation damage
- Significant repair costs
- May have to rebuild house

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Example Single Family Home

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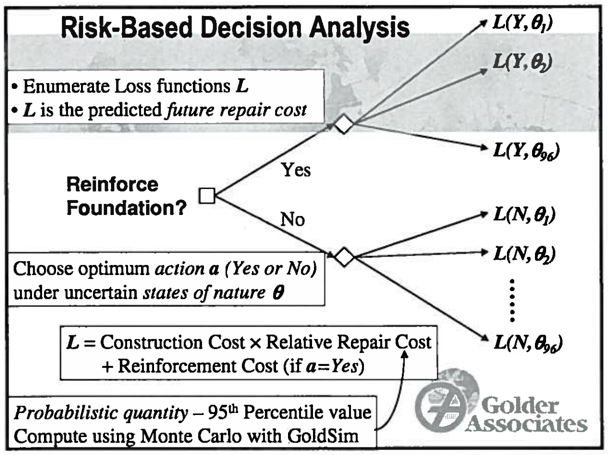
Risk Mitigation: Structural Reinforcement


Layout of 96 houses on lot

Cannot perform ground mitigation for this lot
Do we need to perform structural mitigation?
Answer: **YES** or **NO** for each house

Risk-Based Decision Analysis



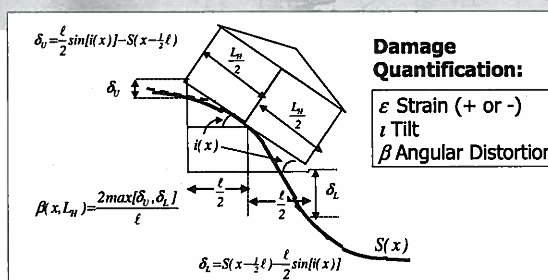
Probabilistic Nature of Model Outputs

- Will a subsidence event occur over next 50yrs?
- When will it occur?
- What is the magnitude of subsidence? ← **Physical Model**
- How much damage?
- Cost of repair? ← **Consequence Model**

Physical Model

- Geotechnical model based on standard equations for strain, tilt and angular distortion of ground
- Peng and Luo (1993) SME Transactions
- Add uncertain inputs:
  - Measured geotechnical quantities
  - Timing subsidence events occurring in 50 yr period
  - Maximum available subsidence – varies in practice

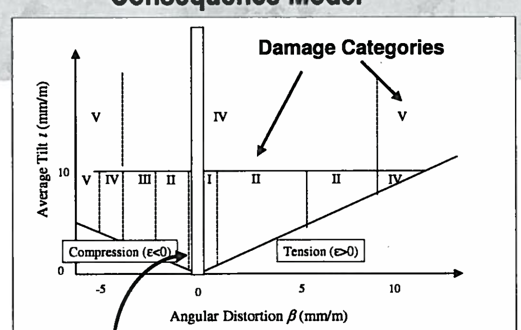
Physical (Geotechnical) Model



Consequence Model

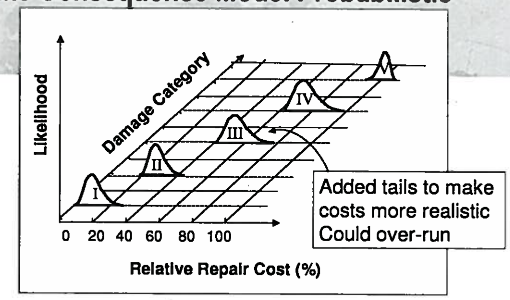
- **Based on work of Marino and Mahar Trans SME (1986)**
- **Relate geotechnical parameters to Relative Cost of Repair (RRC)**
- **RRC placed on a Damage Category Scale (0,I,…,V)**
- **0 – No Damage**
- **V - Cost of Replacing Entire House**

Consequence Model



For structurally mitigated house – assume β=0

Make Consequence Model Probabilistic



Map damage categories to probabilistic range of Relative Repair Costs

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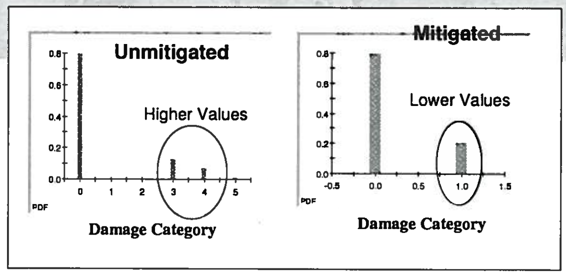
Repair Cost Results for $600K House



Mean Repair Cost on $500K House:
$30K (Unmitigated)
$2K (Mitigated)

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Decision Results

- Fed 95th %tile Relative Repair Cost into Decision Calcs (Loss Function)
- Note: only 38 Houses of 96 were undermined
- Model predicted that 22 of 38 needed no mitigation (Action = No)
- Conservative (deterministic) approach would be to mitigate each house
- Cost of mitigation ~ $10,000 per house
- Using risk-based decision analysis led to potential savings of ~$220K
- Over 5-fold return on investment to client

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Benefits of Risk-Based Approach

- Saves Client Money
- More realistic – better "peace of mind" for client
- Accounts for uncertainties explicitly
- Quantifies subsidence damage for 50 yrs into future
- Gives insurer $-value for insuring properties for 50 years against subsidence damage

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The Team

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