Thermal Modelling of Soil in Earth-Sheltered Structures

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Abstract - This paper introduces a research project, which aims to model the effect of a flame front on a saturated earth berm sheltering a structure. FLAC 3.3 software is to be used to develop the theoretical models. Earth-sheltered structures are known for their energy efficiency. They offer other advantages including protection from natural hazards. Models simulating the behavior of earth sheltered structures in wildfires (bushfires) will be studied. Monitoring of the soil and atmospheric conditions at an earth-sheltered house in Gembrook, Victoria is soon to begin. Other sites may be monitored as the project develops. This data will be used to calibrate the theoretical models. This study should produce guidelines as to the dimensions of a berm, constructed from a "real" soil, which will keep a structure habitable during a bushfire. Risk assessment of this mode of construction in fire prone areas will be quantified. This study may also lead to the modelling and design of earth-sheltered storage structures for fuels or chemicals in fire prone areas.

1. Introduction

In North America, FLAC 3.3 software is used to model the freezing and evaporation of water in soil and optimise basement design for depth and insulation thickness. It is proposed to model the inverse of this situation, the effect of a flame front on a saturated earth berm sheltering a structure.

FLAC (Fast Lagrangian Analysis of Continua) is a two-dimensional, explicit finite difference code. It is capable of transient and steady state thermal analysis using implicit or explicit methods. (1) It is anticipated that a combination of both implicit and explicit methods will be utilised to produce the optimum model

2. Earth-sheltered Buildings

Earth-sheltered buildings, while not yet common in Australia, are steadily becoming more popular. Notable large scale examples include the New Parliament House in Canberra and the Brewarrina Aboriginal Cultural Museum. Currently under construction, in Sydney, is the new earth sheltered Woollahra City Council Chambers. This is being constructed adjacent to the existing historic building. There are also a small number (at least 30-50) of earth-sheltered homes being built each year. (2) These are usually built in rural or semi-rural (and often bushfire-prone) areas.

Earth-sheltered buildings offer many benefits including:

- Energy Efficiency -- little or no heating and cooling costs.
- Unobtrusive, blending into the landscape; there is an earth-sheltered Rangers Residence at Lake St. Clair National Park (Tasmania) which is effectively invisible until you are almost on top of it.
- Low maintenance.
- Preserves open space; earth-sheltered buildings have been designed and built in Europe and the USA for schools, museums, university buildings
- Protection from noise pollution; a public housing project in Minneapolis was successfully designed to minimise noise from an expressway directly behind the development. (3)
- Protection from hazards such as high-intensity storms, earthquakes and wildfires. Underground structures provide resistance to seismic movement due to a number of factors inherent in their design; large earth loadings used in design and the natural movement of the structure with ground motion lessens the "amplification of ground motions by structural oscillation". (4)
- Studies on earthquake effects on underground structures [Gao, (1984) (5) and Loofbourow, (1985) (6)] and earth-sheltered buildings [Lowing, (1984) (7)] support the superior resistance of subsurface structures. Eighty percent of the recently completed Miho Museum in Japan is below ground, chiefly because of the strict local seismic and environmental regulations. (8)

3. Wildfires

Wildfires (bushfires) cause immense damage to people, property and the environment every year. The 'Ash Wednesday' fires in 1983 resulted in the death of 76 people and property damage in excess of $440 million. (9) Wildfires also regularly threaten life and property in the US, Canada, South Africa and the Mediterranean countries.
Earth-sheltered buildings have been given qualitative approval for use in bushfire prone areas by Standards Australia, CSIRO (10) and other sources. (11) This approval is primarily based on the non combustible characteristics of soils. Few, if any, quantitative studies appear to have been performed.

Krarti and Claridge (1990) developed a semi-analytical method for analysing heat exchange between soil and rectangular earth-sheltered buildings. (12) A number of studies have been performed on the thermal performance of these structures, but the emphasis tends to be on heat loss in cool climatic conditions. How does a heat front from an intense, transient source move through an earth wall?

4. The Gembrook House Project

An associated project is the monitoring of an earth sheltered house in Gembrook, Victoria. This project involves the monitoring of soil temperature and moisture levels in the earth berm and roof of the house. External and internal air temperature and humidity both internally and externally will also be monitored.

Thermocouples and Buriable TDR (Time Domain Reflectometry) Wave guides were installed during construction. The thermocouples were laid in 15 mm diameter UPVC conduit to give additional protection from impact or flexural damage. Where instruments were buried at any depth, the necessary pits were backfilled and compacted in layers. A final layer of bentonite was used to mitigate any concentration of moisture due to changed drainage conditions in the disturbed soil. Instrumentation to measure air temperature and humidity both internally and externally is also to be installed. Monitoring is expected to commence in late 1997.
The monitoring program should provide soil temperature and moisture profiles, which will aid in the calibration (matching) of the models. Should a bushfire occur during the monitoring period, some extremely useful data will be obtained.

The body of the house is constructed of reinforced concrete, monolithically poured using a patented reusable modular form work.

The design of the Gembrook house incorporates a number of Passive Annual Heat Storage (PAHS) principles. Passive Annual Heat Storage is a series of techniques designed to maintain a desirable average air temperature. The structure and the surrounding earth interact in such a way as to ensure that internal temperatures remain within a few degrees of the desired temperature at all times. (13) This can eliminate the need for supplementary heating and cooling even in extreme climates. After construction, a 'settling' period is necessary for the earth/structure to stabilise. Existing sources (14) make recommendations only for North American conditions. Data from this project is also to be used in a study of PAHS stabilisation for Australian conditions.

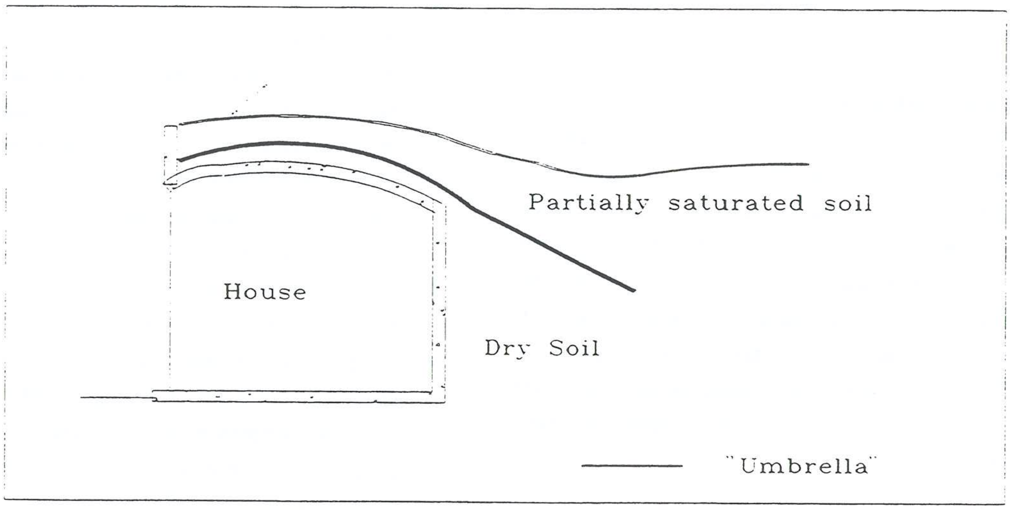

Figure 1 — Section through Earth-sheltered House in Gembrook, Victoria.

The design of the Gembrook House involves an insulating "umbrella" laid over a layer of compacted soil, during the construction process, forming a dry soil "heat bank" after a suitable period of drainage. This will result in a layered soil profile comprising, from the concrete structure of the roof upwards:

- dry (or nearly dry) soil,
- insulating layer (2 layers of heavy duty builders plastic sandwiching a thick layer of spoiled hay), and
- Partially saturated soil subject to normal surface conditions. (Refer Figure 1, below.)

There are many variations of wall profile possible. Further models for a representative sample of wall profiles are envisaged. These would include models for earth sheltered structures and possibly other earth wall types such as pise (rammed earth) and adobe (mud brick).

5. Conclusion

This study should result in a greater understanding of the movement of heat fronts through earth walls. Guidelines will be produced as to the dimensions of a berm, constructed from a "real" soil, which will keep a structure habitable during a bushfire. The "real" soil properties used in this modelling will include porosity, density, and initial degree of saturation.

Risk assessment of this mode of construction in fire prone areas will be quantified. This study may also lead to the modelling and design of earth-sheltered storage structures for fuels or chemicals in fire prone areas.

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