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FIRE SAFETY AND ESCAPE STRATEGIES - ROCK CAVERN STADIUM

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Abstract

The world's largest rock cavern stadium for public use has been built at Gjøvik in Norway as an attractive arena for the Winter Olympic Games in 1994. The cavern stadium has a length of 100 m, width of 61 m and height of 25 metres and is the reference subject in a national ongoing research programme to verify the knowledge and technology related to preinvestigations, planning, construction and use of such rock caverns. The results from this research programme will be used as a basis for updating the national codes of practice concerning large underground spaces for public use.

This paper deals with the fire safety and the escape strategies and how these have been taken into account in this facility assuming that the maximum of 5800 people are in the cavern stadium. Situations with sporting arrangements and alternative uses of the arena have been studied. Codes of practice related to the design of escape routes, smoke detection and smoke control developed for outside buildings could not be put into effect for this kind of plant without necessary adjustments being made.

The actual design have a "*safe area*" surrounding the spectator area. In case of fire in the spectator area evacuation will be from spectator area to this "*safe area*". The "*safe area*" is designed with a minimum area per person of 0.6 m^2.

To make sure that this remains a "*safe area*" if there is a fire in the spectator area, restrictions have been imposed concerning the types of materials which can be used as well the activities permitted. No combustible or hazardious materials are ever permitted in this area.

As far as smoke movement and the design of the smoke control system are concerned both zone-models and numerical computerized fluid dynamic calculations have been carried out with fire scenarios located in the spectator area, alternatively in the sports arena itself.

The overall strategy for the design of the smoke control system is that no smoke should ever be let into the spectator area, into the surrounding "*safe area*" or infiltrate any of the three tunnels. If fire should occur in the car park below, a seperate extraction system is designed to start to control the movement of smoke.

THE GJØVIK OLYMPIC MOUNTAIN HALL

As one of the subsites for the Winter Olympic Games at Lillehammer in 1994, a cavern stadium is now being built at Gjøvik 100 km north of Oslo, the capital of Norway. This is the largest cavern in the world for public use with a span of 61 metres, a length of 100 metres and a height of 25 metres. The rock cavern is connected to the outside by a 100 metre long tunnel leading directly from the main street in the town of Gjøvik.

The cavern stadium is initially designed for Ice-hockey with a maximum number of 5800 spectators. In the period after the Olympic Games in February 1994 it will be used for different types of events like concerts, congresses and various kinds of exhibitions.

Many countries have experienced construction companies and others that have know-how concerning caverns in rock such as hydropower stations and sewage plants. However, in recent years ideas about the multiplex utilization of underground space have been presented in many countries in and outside Europe. The realization of such plans depend on a lot of factors like climate, illumination and acoustics, fire safety and disaster prevention, as well as how these factors together influence the well being of people who remain underground for a matter of hours.

This paper presents the results from fire safety studies and the outline of evacuation tests related to the Gjøvik Olympic Mountain Hall. Our current research is aimed at finding how these results could be used as a basis for the future development and use of computer models combining risk analysis and evacuation studies.

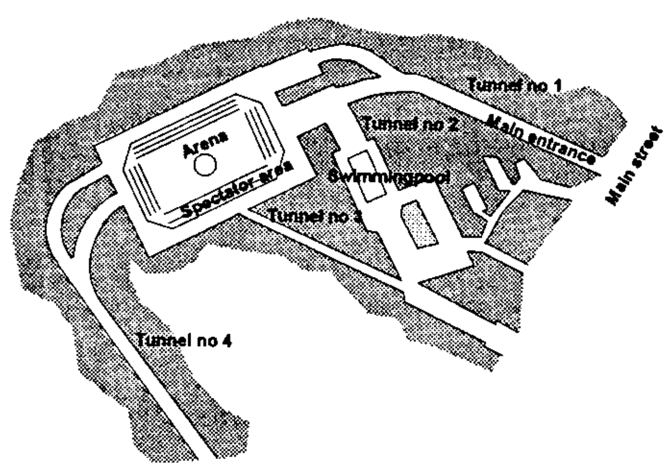

Figure 1. Gjøvik Olympic Mountain Hall. The arena and the spectator area are normally occupied areas. In case of fire, this is assumed to start in one of this areas. In the surrounding area including the tunnel 1-4, the extent of combustible and hazardious materials is highly restricted. The smoke control system is designed to keep the surrounding areas free from smoke by extracting air from the spectator area/arena and supplying air through the tunnels .

VENTILATION

The ventilation of the spectator area is designed with a ventilation-by-displacement system as an alternative to ventilation by complete mixing. Applying this method of ventilation, implies that air is supplied at low levels and extracted near the ceiling utilizing the buoyancy forces to create a thermal stratification. In this design, air is let into the spectator area through the openings from the surrounding hall as well as from devices located at the upper level of the arena. Extraction devices are located beneath the ceiling. Figure 2.

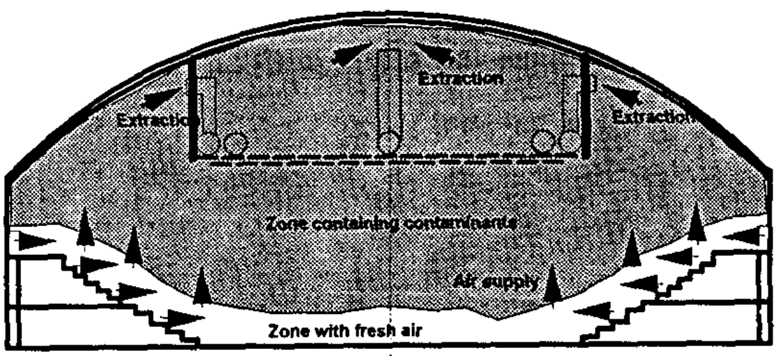

Figure 2. Spectator area. Ventilation-by-displacement

ESCAPE ROUTES

Initially underground spaces for public use like this rock cavern are more dangerous in case of fire because they are closed spaces with few, long distance escape routes.

With daylight buildings a lot of research has focused on fire safety through the proper design of escape routes according to codes and guidelines describing the size of the area and net width. Basically these criteria can be applied to rock caverns for public use as well. In practice, geotechnical aspects make it necessary to design solutions which provide adequate safety without excessive cost.

Therefore to achieve the same standard of safety as in daylight buildings, there should be "safe areas" inside such underground spaces.

No combustible or hazardious materials should ever be allowed to be used or stored in the "safe areas". With a properly designed smoke ventilation system, it is possible to maintain these areas without smoke when there is a fire. Attention should always be paid to the refinement of the operating and maintenance procedures for these life safety systems.

Table 1. Total and net width of the main and emergency tunnels (ref 6). Tunnel numbers are shown in Fig. 1.

The Gjøvik Olympic Mountain Hall	Total net width of tunnel openings (inside) (m)	Total net width of tunnel openings (outside) (m)
Tunnel no 1	8	8
Tunnel no 2	6	3.5
Tunnel no 3	4	3.5
Tunnel no 4	4	4
Total	**22**	**19**

For daylight buildings the code of practice for the design of escape routes in Norway, as in many other countries is that the number of occupants should not exceed 150 per metre net width.

Applying the code of practice to the figures in Table 1, the number of occupants should either not exceed 2850 or the net width of the openings should be exceeded by up to approximately 39 metres if the number of occupants are 5800.

This situation would give the underground alternative a disadvantage as far as costs and constructional work are concerned.

The introduction of inside "safe areas" is one way of solving this problem. Through the design of inside "safe areas" evacuation is guided to "safe areas" inside the plant without using the tunnels.

People are supposed to stay in the "safe area" until they are guided to outside by the loudspeaker system/guards, and the main tunnels are primarily in use by fire-personell in the early stage of a fire.

The "safe area" is introduced to the actual design as shown in Fig. 3. In case of fire in the spectator area evacuation should proceed from the spectator area to the "safe area" through the ten openings, 1-10.

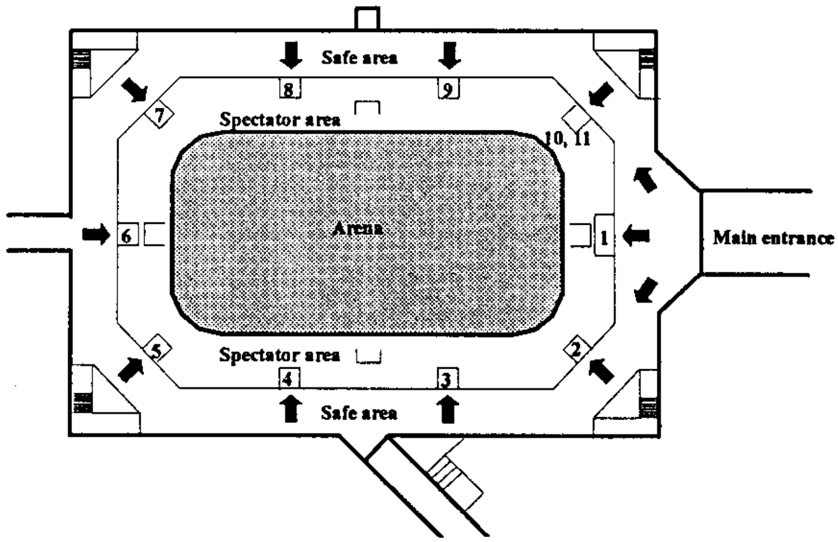

Figure 3. "Safe area".

Table 2. The EXIT openings from spectator area to the "safe area".

The Gjøvik Olympic Mountain Hall	Total width
EXIT opening no 1	6.4 m
EXIT openings no 2-9	8·4.3 m
EXIT openings no 10-11	2·2.0 m
Total	46.8 m

The "safe area" totals about 3500 m^2 leaving about 0.6 m^2/person in case of complete evacuation of the spectator area.

EVACUATION TIME

The evacuation time i.e.the total time needed for the crowd movement to occur from the spectator area to the "safe area", is estimated on the basis of three different empirical correlations.

$T = (P/(W*1.25))$ (s)	ref 1	[1]
$T = (W_e/(P*8.04))^{(-1/1.37)}$	ref 1	[2]
$T = P/(0.206*W_e*(P/W_e)^{0.27})$	ref 1	[3]

T	= evacuation time (s)
P	= number of occupants (-)
W	= total width of opening (m)
W_e	= net width of opening (m)

Eq. 1 is based on measurements at the Amsterdam Stadium and a sports arena in Los Angeles.

Eqs. 2 and 3 are correlations based on measurements from several types of buildings.

The egress movement is by Jake L.Pauls ref. 7, estimated to be 0.6-1.0 m/s through corridors.

The surrounding "safe area" can be reached from the spectator area through ten openings with a total net width of W_e = 46.8 m

THE SMOKE CONTROL SYSTEM

In case of fire in the spectator area, smoke will be extracted by using an extraction system with a designed capacity of about 80 m^3/s. The airflow temperature through this extraction system should never exceed 70 degr. Celsius. The system will be activated from smoke detectors located beneath the ceiling. From that time on, the air supply system will be stopped and air will be supplied from the outside through the main tunnel (no.1) as well as through the two emergency tunnels (no.2 and no.3). The strategy with the mechanical smoke ventilation system implies that evacuation from the spectator area always will be in a direction against the inflowing air. The air flow pattern is verified by using computerized fluid dynamic calculations[1] as shown in Fig. 4. The fire development i.e. heat output in kW versus time, for these simulations is based on full scale fire tests [9].

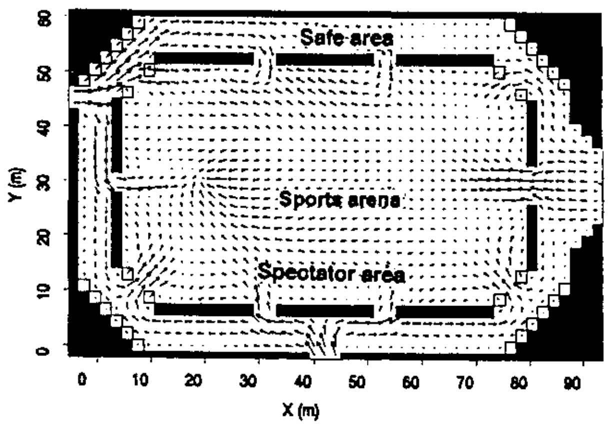

Figure 4. Air flow pattern

FIRE SCENARIOS

Different kinds of simulations are carried out both with zone-models as well as by using a CFD-model to study the smoke movement in the spectator area in case of fire. Fire scenarios in different locations related to the following situations are studied: ice-hockey/handball, concert/congresses and exhibitions. The results are related to the estimated evacuation time as shown in Tables 4, 5 and 6.

Table 3. Number of occupants in each scenario

Scenario	Number of occupants spectator area	Number of occupants arena
1) Ice-hockey, handball	5800	-
2) Concerts, congresses	3660	1440
3) Exhibitions	-	1200

FIRE SAFETY

In the following, the estimated evacuation time is related to the time when the descending smoke layer reaches the upper level of the spectator area, $t_{12\,m}$, assuming that the upstreaming hot smoke forms a smoke layer beneath the cealing which due to heat transfer to the surroundings tends to decend.

Table 4. Fire located in the spectator area during ice-hockey/handball matches.

Scenario 1	Evacuation time(s)	$t_{12\,m}$ (s)
Eq 1	73	800
Eq 2	129	
Eq 3	136	

Table 5. Fire located in the arena during concerts/congresses. In this situation some of the spectators (number of seats are 3660) are evacuating from the arena via the spectator area to the "safe area", while people sitting in the spectator area (number of seats are 1440) are evacuating directly to the "safe area" through the connecting doors.

Scenario 2	Evacuation time(s)	Evacuation time(s)	Total	$t_{12\,m}$ (s)
	3660 occupants from spectator area to "safe area"	1440 occupants from arena to the spectator area		
Eq 1	92	95	187	570
Eq.2	155	190	345	
Eq.3	164	202	366	

Table 6. Fire located in the arena during an exhibition.

Scenario 3	Evacuation time (s)	$t_{12\,m}$ (s)
	1200 occupants from the arena to the "safe area"	
Eq 1	56	$t_{12\,m} > 350$
Eq.2	128	
Eq.3	136	

Results from CFD simulations, scenario 1, 2 and 3, are shown in Fig 5, 6 and 7

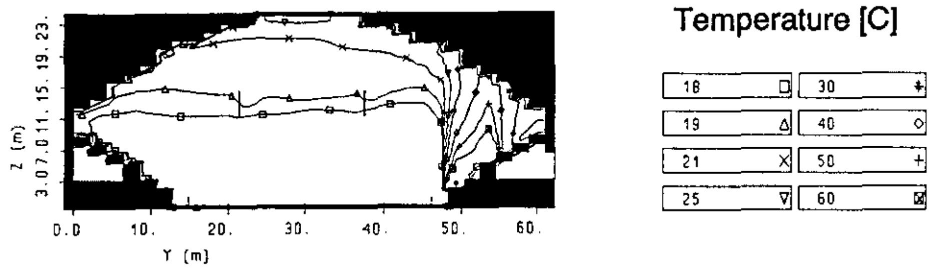

Figure 5. Scenario 1. Smoke layer t = 800 s

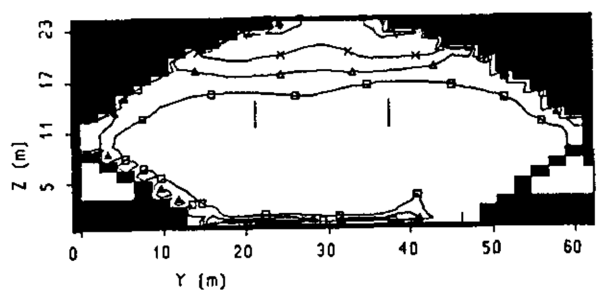

Figure 6. Scenario 2. Smoke layer t = 570 s

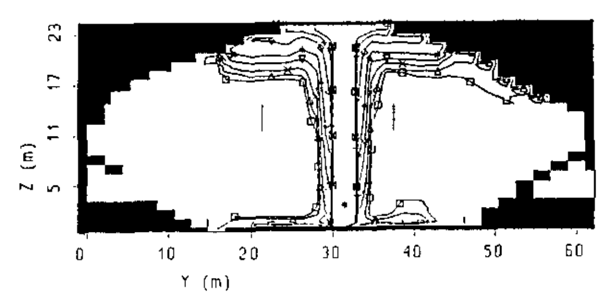

Figure 7. Scenario 3. Smoke layer t = 350 s

These studies only deal with fire safety in the period from when the fire alarm is activated until evacuation from the spectator area and the arena is completed. In a real fire situation this fire will most probably initiate fire in surrounding materials i.e in the exhibition situation. This situation will require special efforts as far as fire fighting and extinguishing is concerned. This is dealt with in a current separate study.

FURTHER WORK

As this stadium will be one of the subsites during the Winter Olympic Games in 1994, tests with real individuals are planned to study the crowd movement under evacuation.

During these tests observations will be recorded by video cameras with time registration. As a part of an ongoing research project these results will be related to those presented here as well as results from future simulations with evacuation models.

CONCLUSIONS

The use of underground facilities for public use is increasing all over the world. Multiplex utilization of underground space i.e for multifloor-shopping centres, concert halls, sports arenas are all relevant. The realization of such plans depend on a lot of factors like climate, illumination and acoustics, fire safety and disaster prevention, as well as how these factors in combination, influence the well being of people who are underground for a matter of hours.

The code of practice concerning the area required in the design of escape routes for daylight buildings cannot always be applied to underground facilities for public use, both from cost, constructional and geotechnical reasons.

Current research related to the construction of the Gjøvik Olympic Mountain Hall in Norway is dealing with topics like fire safety and evacuation strategies by the utilization of inside "safe areas".

Detailed studies of smoke movement are to involve both zone-models as well as computational fluid dynamic calculations. The results are used in the design of the mechanical smoke ventilation system ensuring that smoke will never contaminate the "safe areas".

For the actual design the smoke movement related to three different fire scenarios located in the spectator area is related to estimated evacuation times to ensure that the crowd movement from the spectator area to the "safe area" will be completed before the descending smoke layer will have any influence.

The evacuation strategy and the estimated evacuation times will also be compared with results with the evacuation of real individuals. These tests are planned to be carried out before the end of this year.

ACKNOWLEDGEMENTS

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