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Category

Research Article

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Large fuel tanks are located in an urban area of Tsing Yi in Hong Kong, giving potentially high risks to people living nearby if a fire was to occur. Scale modeling experiments were carried out to investigate the potential of fire hazards. Propanol pool fires with five different scales of oil tanks were studied first. Appropriate tank sizes were then put in a 1/2500 architectural scale model on the Tsing Yi Island to study a fuel tank fire. Results show that the heat and smoke from a fire would affect occupants staying in areas near to the fuel tanks. Fire safety provisions in the storage areas must be demonstrated to function satisfactorily in big fire scenarios and upgraded when necessary. Emergency evacuation plans should be worked out to reduce the potential risk of having big disasters.

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A study on fire hazards of oil tanks in urban areas with scale model experiments

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Abstract

Large fuel tanks are located in an urban area of Tsing Yi in Hong Kong, giving potentially high risks to people living nearby if a fire was to occur. Scale modeling experiments were carried out to investigate the potential of fire hazards. Propanol pool fires with five different scales of oil tanks were studied first. Appropriate tank sizes were then put in a 1/2500 architectural scale model on the Tsing Yi Island to study a fuel tank fire. Results show that the heat and smoke from a fire would affect occupants staying in areas near to the fuel tanks. Fire safety provisions in the storage areas must be demonstrated to function satisfactorily in big fire scenarios and upgraded when necessary. Emergency evacuation plans should be worked out to reduce the potential risk of having big disasters.

Keywords: Scale modeling tests; Tank fires; Urban areas; Disaster management

Introduction

Oil tanks [1–3] were allocated on the Tsing Yi Island before developing the areas about fifty years ago. That area was an isolated island with a power plant, fuel tanks, storage areas, factories and shipyards, with a low population density. It is now an urban area linked up by bridges and tunnels with the Kowloon peninsula. More importantly, the area is below the flight path of the busy airport. Many public estates and private apartments are located nearby as shown in Fig. 1a and b. However, the fuel tanks are not yet moved out, though a power plant was removed to provide better air quality. The large volume of flammable fuel tanks and liquefied petroleum gas (LPG) storage near the residential areas has led to public concerns for over ten years.

The storage tanks are claimed to be sufficiently safe [1]. However, is a fire accident occurred, a potential big disaster would ensue. For example, in the past decade many tank fire accidents have occurred around the world including the Buncefield Incident in 2005 and Jaipur oil depot fire in 2009. A serious explosion in Tianjin in 2015 [4] was related to the improper and excessive storage of flammable and toxic chemicals. From the investigation conducted by the British government, the major cause of the Buncefield Incident was the leakage of gasoline which mixed with air to give flammable vapor clouds and an explosion occurred [5]. Similar hidden hazards on the Tsing Yi Island should be watched carefully and actions taken if necessary to eliminate the potential for a disaster.

With reference to local code and a report [6, 7], an earlier study [8] in 2012 indicated that after an accidental fire occurred in one of the fuel tanks located on the Tsing Yi Island, the possible fire in burning the fuels stored could reach 250,000 MW. The possible heat flux at nearby highways, residential buildings and schools could be up to 60 kW/m^2 [4, 8, 9]. Such an event would be disastrous to residents in nearby areas, and may even disturb the normal operation of the airport. The public has expressed their concern about the large amount of flammable fuel tanks and liquefied petroleum gas (LPG) stored on Tsing Yi Island [8]. They worry about the potential dangers and hazardous consequences of these fuel tanks. This paper reports a preliminary attempt to explore the potential hazards of fuel tanks located on the Tsing Yi Island with physical scale models for developing a better understanding of the potential hazards to residents.

Potential hazards

Based on the data from literature [10], the ranges of

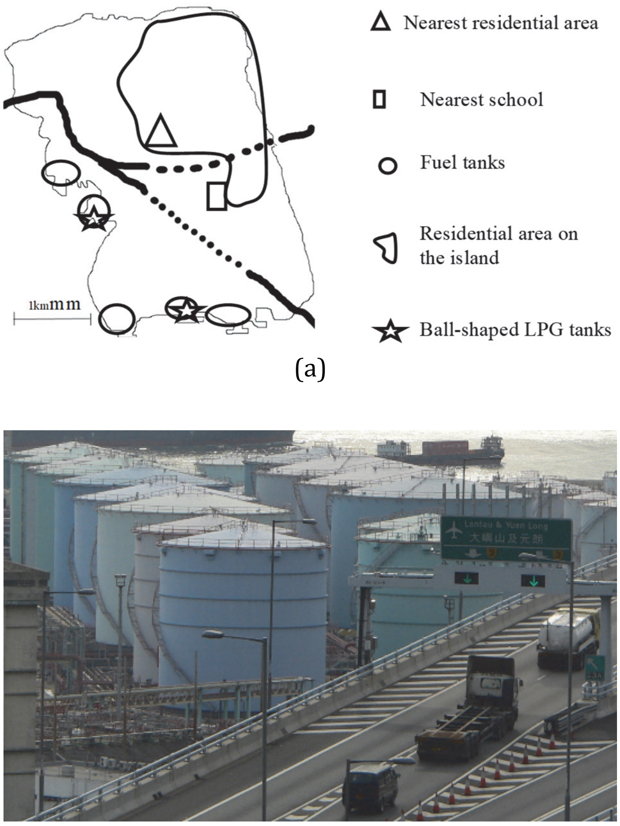


Fig. 1. Tsing Yi Island. (a) Layout (b) Fuel tanks next to highways with heavy goods vehicles passing through.

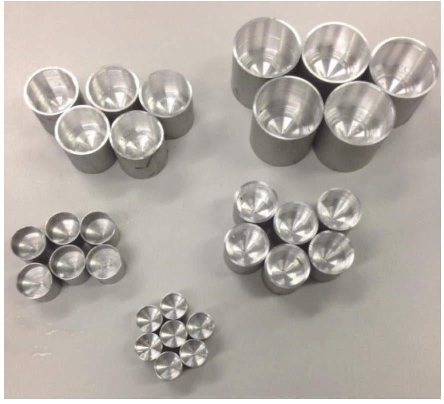


Fig. 2. Five sets of scale containers.

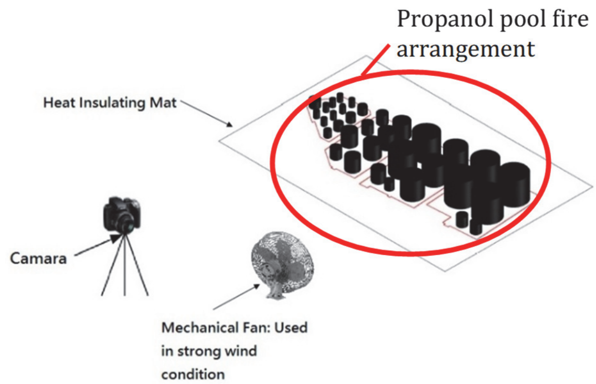


Fig. 3. Propanol pool fires.

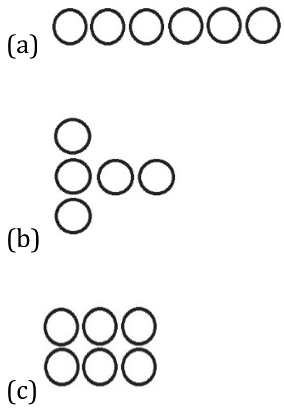


Fig. 4. Oil tank model arrangements. (a) Linear (b) T-shape (c) Two by three.

possible fire sizes for the LPG stored on the Tsing Yi Island were estimated to be 2,300 MW for a pool fire of 500 m^2, and 425,000 MW for 104,200 m^2.

The possible heat flux imposed on the nearest highways, residential buildings and schools would be between 7 kW/m^2 to over 60 kW/m^2. On top of the thermal impact, the fire ball and smoke plume in such a big fire would severely affect the people, vehicles and planes in the area.

To assess potential hazards of the fuel tanks on the Tsing Yi Island, a series of scale model experiments were performed with reference to literature results on mass fires with large fuel loads [e.g., 11]. Reliable results are possible by studying the fire pattern in a model for a mass fire [11]. The scaling factors were determined to be 0.05 m × 0.002 m^2 (1/500), 0.037 m × 0.001 m^2 (1/800), 0.03 m × 0.0007 m^2 (1/1000), 0.025 × 0.0005 m^2 (1/1500) and 0.018 m × 0.0003 m^2 (1/2000). A scaling factor of 1/2,500, linear scale model of the Tsing Yi Island was designed and fitted in the space of our fire laboratory.

Arrangement of propanol pool fires

Propanol pool fires near oil tanks with five different sizes were studied. Fire spreading patterns were analyzed to enable selection of an appropriate scale for the physical modeling tests. It is to be noted that container arrangements, particularly the distance between each tank, is a key factor affecting fire spread across the tanks [12].

An oil depot model storing the highest amount and densest number of fuel tanks inside the station was used. Five different sets of containers, as shown in Fig. 2, were tested according to the tank arrangement at the depot. A three-dimensional layout of the test is shown in Fig. 3.

Table 1. Summary of the tests.

Test Number	No wind	With Wind
S1	– All the containers were ignited at the end of the test. – The total burning time is about 60 minutes, which is time consuming. – The scale of those containers is too big, which consumes lots of fuel.	– All the containers were ignited at the end of the test. – The total burning time is about 20 minutes under strong wind condition, which is acceptable. – The scale of those containers is too big, which consumes lots of fuel.
S2	– Only the four biggest containers were ignited at the end of the test, which is not acceptable for fire spreading pattern study.	– All the containers were ignited at the end of the test. – The total burning time is about 4 minutes. – The scale of those containers is feasible, which does not consume so much fuel.
S3	– All the containers were ignited at the end of the test. – The total burning time is about 42 minutes, which is time consuming. – The scale of those containers is too big, which consumes lots of fuel.	– All the containers were ignited at the end of the test. – The total burning time is about 15 minutes under strong wind condition, which is acceptable. – The scale of those containers is too big, which consumes lots of fuel.
S4	– About half of the containers were ignited at the end of the test. – This is not acceptable for fire spreading patter study.	– All the containers were ignited at the end of the test. – The total burning time is about 7 minutes. – The scale of those containers is feasible, which does not consume so much fuel.
S5	– All the containers were ignited at the end of the test. – The total burning time is about 30 minutes, which is appropriate. – The scale of those containers is quite suitable, which would not consume lots of fuel.	– All the containers were ignited at the end of the test. – The total burning time is about 10 minutes under strong wind condition, which is acceptable. – The scale of those container is quite suitable, which would not consume lots of fuel.

Propanol (99% purity) was used as the fuel to fill each set of containers. The biggest tank was ignited by a lighter. Two scenarios were considered, with and without wind, to observe fire spreading patterns of each set of containers. A mechanical fan of flow rate 0.5 m/s was used to simulate wind action.

After selecting an appropriate set of tanks, fire tests were conducted with three tank arrangements: one was linear, one T-shaped and two were two-by-three, as shown in Fig. 4a and b. Fire spreading patterns were recorded and analyzed to determine whether a mass fire would be generated in each tank arrangement.

To identify the most suitable size of the model, five different sets of scales (S_i)were tested with wind-free and strong wind scenarios. These were:

- S1: 0.05 m x 0.002 m^2 (1/500)
- S2: 0.037 m x 0.001 m^2 (1/800)
- S3: 0.03 m x 0.0007 m^2 (1/1000)
- S4: 0.025 x 0.0005 m^2 (1/1500)
- S5: 0.018 m x 0.0003 m^2 (1/2000)

Results of the five tests are summarized in Table 1.

The fuel tank configuration S3 was selected for more investigation because a clear and complete fire spreading pattern was observed. Additional fire tests concentrated on the possibility of the fires merging using the following configurations:

- T1: Linear
- T2: T-shape
- T3: Two by three

Results showed that all three configurations could lead to fire merging that would generate a large fire plume, as shown in Fig. 5.

The measured flame height of a large fire was about 3 times (30 cm) their separated fire flame heights (10 cm). These results indicated that it is highly possible to have a mass fire once a fire occurred in the Tsing Yi Island fuel tank station since the thermal radiation released by a fuel tank must be larger than that by a scale model.

Scale modelling experiment

A 1/2500 scale geographic model of Tsing Yi Island

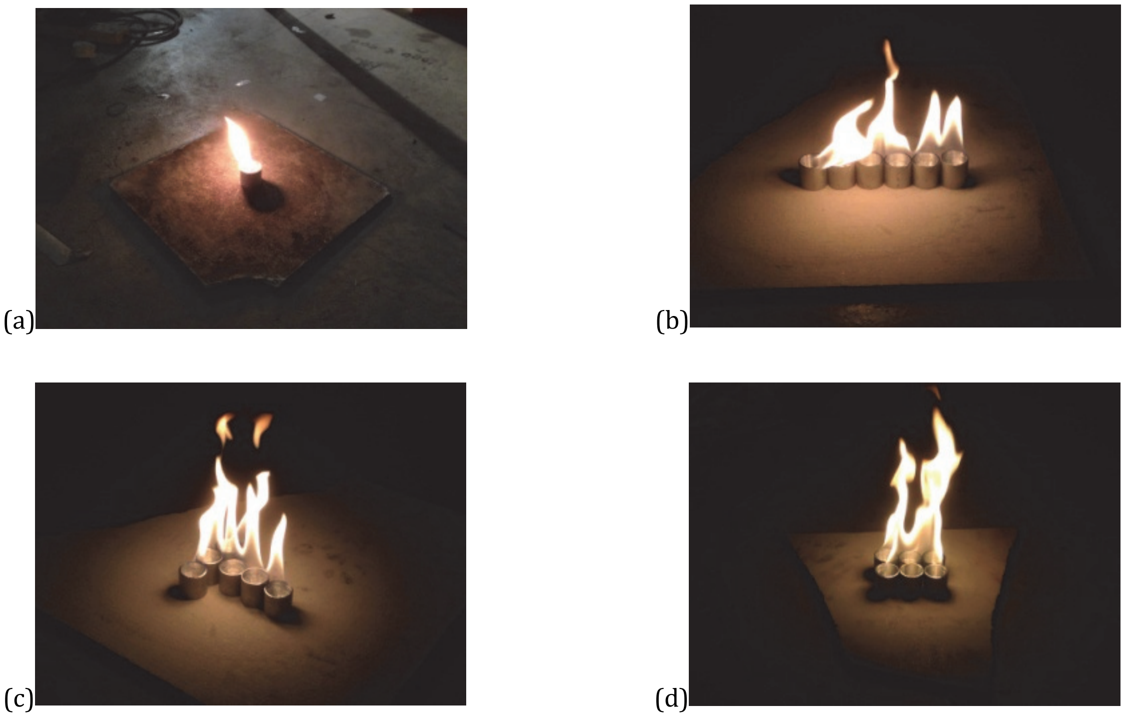


Fig. 5. Burning oil tanks. (a) A single pool (b) T1: Linear (c) T2: T-shape (d) T3: Two by three.

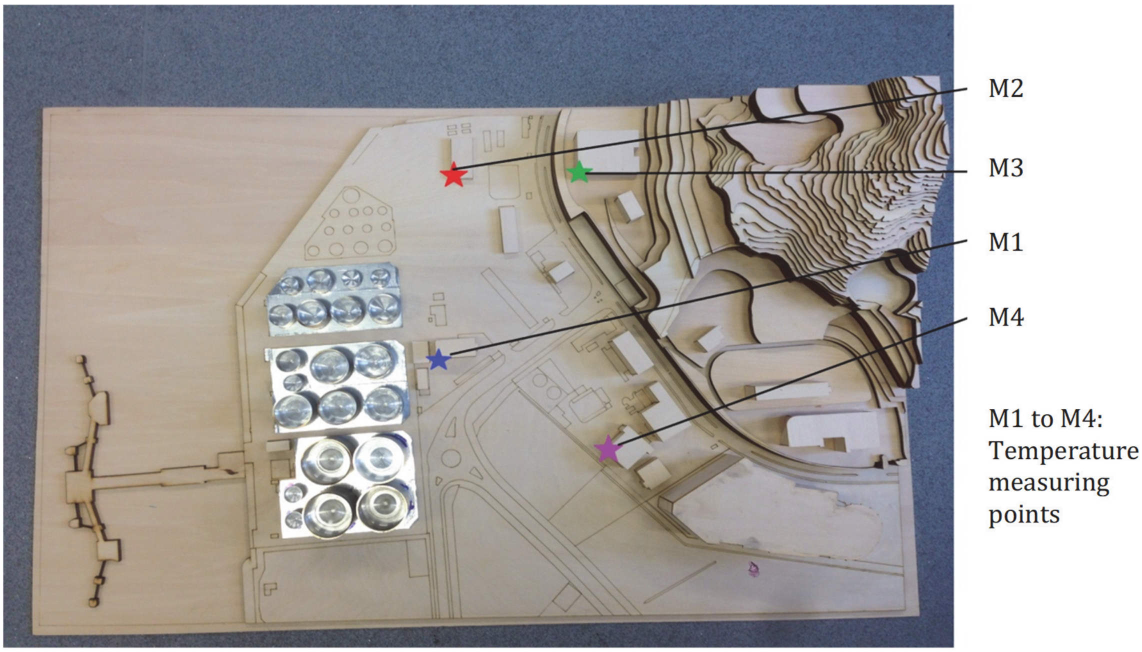
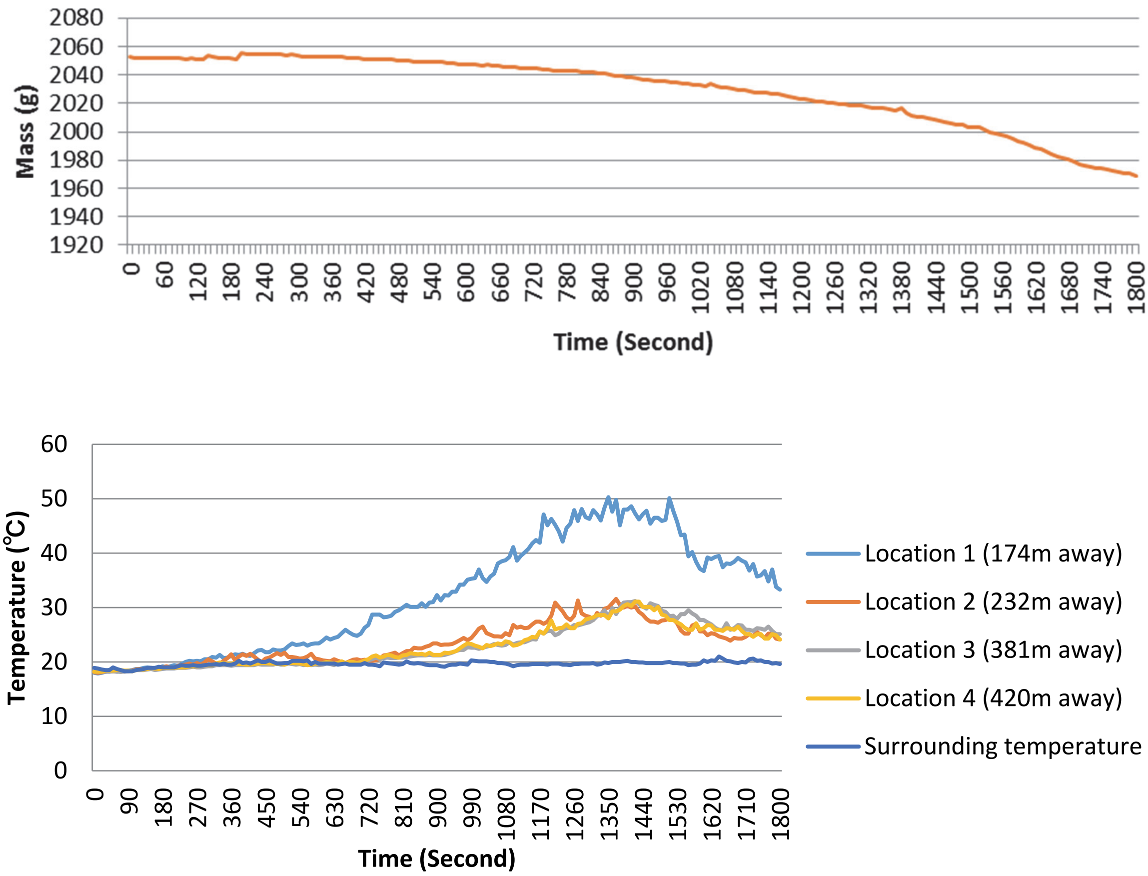


Fig. 6. General view of the Tsing Yi Island model.

was constructed [13]; it was 0.9 m long, 0.6 m wide and of maximum height 0.12 m. The scaling factor of the model was selected from the propanol pool fire tank. The model was made of wood with aluminum oil tanks, as in the oil depot. The geographic model illustrating the setup of the experiment is shown in Fig. 6.

Air temperatures were measured with thermocouples at four positions M1 to M4 as shown in Fig. 6 and propanol (99% purity) was loaded into the aluminum fuel containers. The arrangement of the model tanks basically followed T3, although not exactly the same. The biggest tank was ignited to establish the first burning object; an electronic balance was used to measure the transient fuel mass loss rates during and after burning tests.

The heat release rate Q, surrounding temperature T and wind velocity V between the reduced-scale and full-scale models with scaling factor L_m/L_f of the model [14]



(a)

(b)

Fig. 7. (a) Mass loss rate of fuel (b) Transient temperature at the four locations.

follow the Froude number scaling laws:

$$\frac{Q_m}{Q_f} = \left(\frac{L_m}{L_f}\right)^{2.5} \quad (1)$$

$$T_m = T_f \quad (2)$$

$$\frac{V_m}{V_f} = \left(\frac{L_m}{L_f}\right)^{0.5} \quad (3)$$

The fire load for the fuel was calculated from the heat release rate Q', which is related to the burning rate m' (kg/s/m^2), fire area A (m^2) and specific heat of combustion Δh (MJ/kg) by:

$$Q' = m' \, x \, A \, x \, \Delta h \quad (4)$$

The heat release rate of a propanol pool fire in such a fire test was also estimated by considering propanol has a specific heat of combustion of 33.6 MJ/kg and its total fire burning area was 0.019 m^2. Fig. 7a. From the mass loss curves during burn tests, Fig. 7a, the mass loss rate was nearly linear with a rate of 0.0000462 kg/s/m^2. Hence, the heat release rate of this test in the scale model was 0.0000295 MW, which corresponds to a full-scale model heat release rate of 940 MW; this value is lower than the values estimated for a big disastrous fire [8].

The transient temperatures at the four locations during burn tests are shown in Fig. 7a. Because of equation (2) in which the temperature measured with the reduced-scale model would be equal to the temperature for the real case, the recorded temperatures during scale model testing could approximately represent the real temperature distribution on Tsing Yi Island once the fire occurred. From the results, the highest temperature was 50.3^{o}C at the nearest building from the fire source and the lowest temperature recorded at the same time was 28^{o}C. The surrounding temperature within the fire laboratory was near 20^{o}C.

Conclusions

This paper reports the potential hazards of fuel tanks located on Tsing Yi Island which pose a potential mass fire problem if a fire occurred in the fuel tanks. The temperatures and mass loss rate data acquired during the scale model tests could be used to estimate the maximum temperature in the area surrounding the tanks and the corresponding heat release rates. From the preliminary experiments, the maximum air temperature at the nearest real building at the site could reach 50℃ within 20 minutes even with a relatively small fire of 940 MW. These data indicated that heat could be a major issue for areas adjacent to the tanks; if the fire was more substantial than the one modeled in this manuscript, a seriously hazardous situation would occur. Although the tests were conducted using a reduced-scale geographic model, the results are believed to be useful for identifying potential hazards of the Tsing Yi Island. As there are variations in fire sizes and the validity of estimations, the current practice of fire safety analysis should be improved by considering more situations and outcomes.

Existing fire safety systems in Hong Kong were developed with reference to the UK practices years ago [15]. However, the Buncefield Incident revealed the inadequacy of the systems to stop the fire and to resolve the impacts on the surrounding community. Even bigger explosions [e.g., 16] have occurred due to inappropriate management, and scale modeling experiments could clearly demonstrate hidden hazards and help the planning for appropriate fire safety systems. Fire safety management should be diligent and considerate of all nearby residential areas near fuel storage facilities to ensure that the burning of combustibles in a fuel depot would not generate a very hazardous fire [17, 18]. Hence, scale model experimentation offers the theoretical basis and experimental evidence for ensuring fire protection systems will work in a big fire.

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