International Conference on Hydrogen Safety 2023

# ID 204: Experimental Study on the Effect of the Ignition Location on Vented Deflagration of Hydrogen-Air Mixtures in Enclosure

**2023. 09. 21.**

**Hydrogen infrastructure research cluster,**
**Korea Institute of Civil Engineering and Building Technology (KICT)**

**U.G. YOON**

# History

**Aug. 1948**
Initiated as the Civil Engineering Laboratory Institute of Construction Bureau of the Ministry of Home Affairs

**Jun. 1962**
Reorganized as the National Construction Research Institute of the Ministry of Construction

**Jun. 1983**
Renamed as the National Construction Laboratory Institute of the Ministry of Construction (research function separated)

**Jan. 1988**
Designated as a government-funded research institute of the Ministry of Construction

**Nov. 1997**
Moved KICT headquarters to Ilsan

**Apr. 2006**
Completion of Fire Investigation, Research, Testing and Education (Hwaseong)

**Nov. 2009**
Completion of River Experiment Center (Andong)

**Nov. 2013**
Construction started on the SOC Evaluation Research Center (Yeoncheon, Gyeonggi-do)

**Jul. 2015**
Construction Industry Innovation Center established in KICT

**Jul. 2017**
Designated as a government-funded research institute under the National Research Council of Science & Technology of the Ministry of Science and ICT

# Mission & Function

**Mission**

The KICT contributes to the development of the Korean construction industry, improves quality of life standards, furthers national economic growth, and improves social welfare. We promote original technology in the fields of land, infrastructure, and construction.

**Function**

- Research and Development
- Policy-Making and Technology Support
- Quality Certification and Testing Services

# Organization

- **President**
  - Inter-Korean Special Committee on Infrastructure
  - Audit Department
  - Korea Construction Standards Center
  - **Vice President for Research**
    - Research Strategic Planning Department
    - Health and Safety Office
    - Department of Highway & Transportation Research
    - Department of Structural Engineering Research
    - Department of Geotechnical Engineering Research
    - Department of Building Research
    - Department of Hydro Science and Engineering Research
    - Department of Environmental Research
    - Department of Future & Smart Construction Research
    - Department of Fire Safety Research
    - Department of Building Energy Research
    - Integrated Road Management Research Cluster
    - Modular Construction Research Cluster
    - Smart Cities Research Cluster
    - Hydrogen-Infrastructure Research Cluster
    - BIM Research Cluster
    - The Air Quality of Living Environment Cluster
  - **Vice President for Industrial Innovation**
    - Construction Test & Certification Department
    - Construction Industry Promotion Department
    - Department of Construction Policy Research
    - KICT School
    - The Yeoncheon SOC Demonstration Research Cluster
    - The International Partnerships Cluster
  - Planning and Coordination Department
  - Administration Department
  - International Cooperation and Public Relations Department

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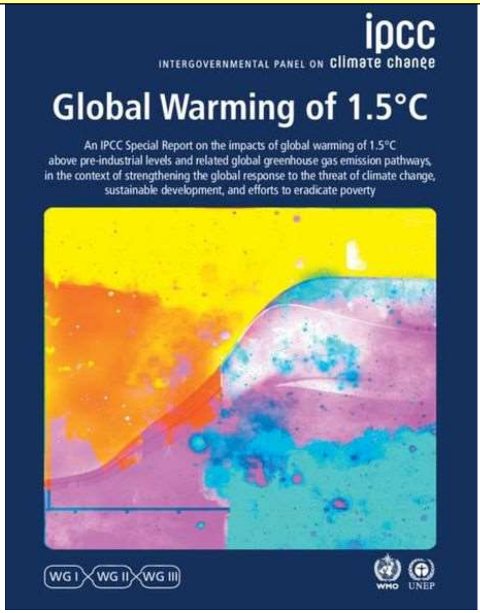
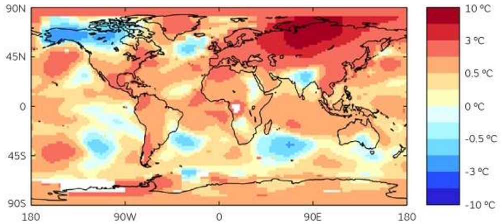
# 1. Introduction



## 1.1 Background of research

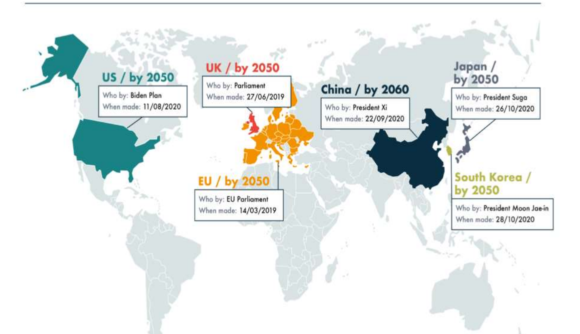
**Special report on global warming of 1.5℃**




The map using data from GISTEMP, Shows temperatures relative to the average between 1981-2010

**Key recent net zero policy commitments**



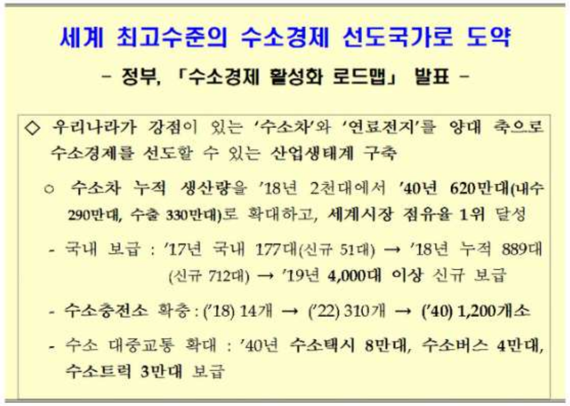

Climate Action Tracker
(https://carbontracker.org/unleashing-the-river-of-change/)

**Hydrogen energy indispensable in the carbon neutrality era**


Monthly people
(https://www.monthlypeople.com/news/articleView.html?idxno=270137)

**The government announced the「Hydrogen economy revitalization roadmap」to lead the hydrogen economy**

| 산업통상자원부 http://www.motie.go.kr | 보 도 자 료 | | 보다 나은 정부 |
|---|---|---|---|
| 2019년 1월 17일(목) 석간부터 보도하여 주시기 바랍니다. (인터넷, 방송, 통신은 1.17(목) 12:00 이후 보도 가능) | | | |
| 배포일시 | 2019. 1. 16.(수) | 담당부서 | 산업통상자원부 에너지신산업과<br>기획재정부 혁신창업팀<br>과학기술정보통신부 원천기술과<br>환경부 대기환경과<br>국토교통부 미래전략일자리담당관<br>해수부 해사산업기술과 |
| 담당과장 | 신성필 과장(044-203-5390)<br>조현진 과장(044-215-4640)<br>김민표 과장(02-2110-2380)<br>박륜민 과장(044-201-6880)<br>배성호 과장(044-201-3258)<br>임현택 과장(044-200-5830) | 담 당 자 | 박성수 사무관(044-203-5398)<br>장준희 사무관(044-215-4573)<br>손효진 사무관(02-2110-2758)<br>김건식 사무관(044-201-6887)<br>유 훈 사무관(044-201-3260)<br>양진영 사무관(044-200-5834) |



**세계 최고수준의 수소경제 선도국가로 도약**

**- 정부, 「수소경제 활성화 로드맵」 발표 -**

◇ 우리나라가 강점이 있는 '수소차'와 '연료전지'를 양대 축으로 수소경제를 선도할 수 있는 산업생태계 구축

○ 수소차 누적 생산량을 '18년 2천대에서 '40년 620만대(내수 290만대, 수출 330만대)로 확대하고, 세계시장 점유율 1위 달성

- 국내 보급 : '17년 국내 177대(신규 51대) → '18년 누적 889대 (신규 712대) → '19년 4,000대 이상 신규 보급
- 수소충전소 확충 : ('18) 14개 → ('22) 310개 → ('40) 1,200개소
- 수소 대중교통 확대 : '40년 수소택시 8만대, 수소버스 4만대, 수소트럭 3만대 보급

❖ The Intergovernmental Panel on Climate Change (IPCC) proposed limiting global warming to 1.5°C above pre-industrial levels, which was adopted in the Paris Agreement, and limiting net carbon dioxide emissions by 2030 by 45% compared to 2010 and net zero by 2050.

❖ 121 countries around the world declared net zero by 2050 and 9 countries legislated net zero (as of Nov 2020).

❖ Korea also announced the Hydrogen Economy Roadmap to use hydrogen as a major source of energy (as of Jan 2019).

# 1. Introduction

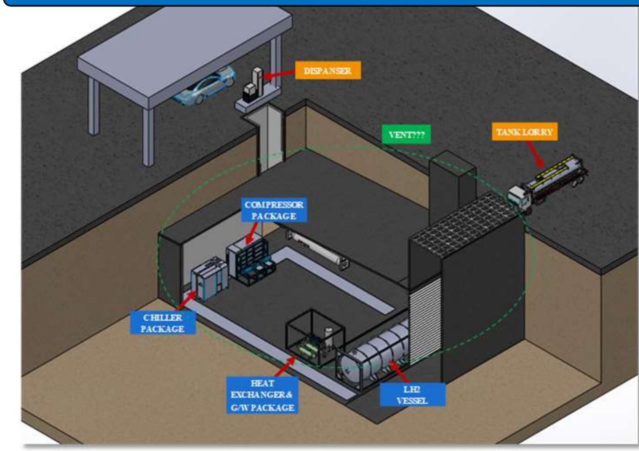


## 1.2 Need for research


Gangneung venture plant
hydrogen explosion accident site


Gunsan hydrogen plant explosion site


Underground liquefied hydrogen station layout (Plan)



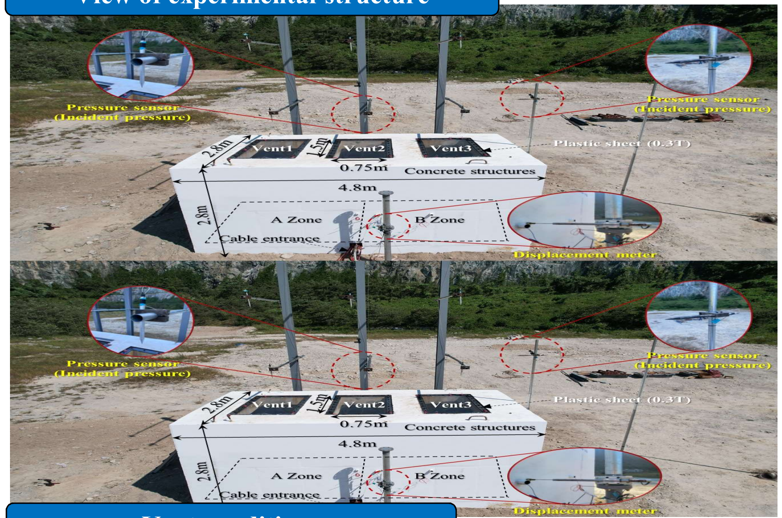

- ❖ Hydrogen infrastructure is built mostly on the ground, which is limited in terms of obtaining enough space in city centers and adjacent areas and causes civil complaints in the city
- ❖ Lack of acceptance in terms of protection, rescue, and safety facilities to mitigate risk in facilitates
- ❖ Lack of measures against potential hydrogen leaks, fires, or explosions in infrastructure, including safe distancing and facility specifications

# 1. Introduction



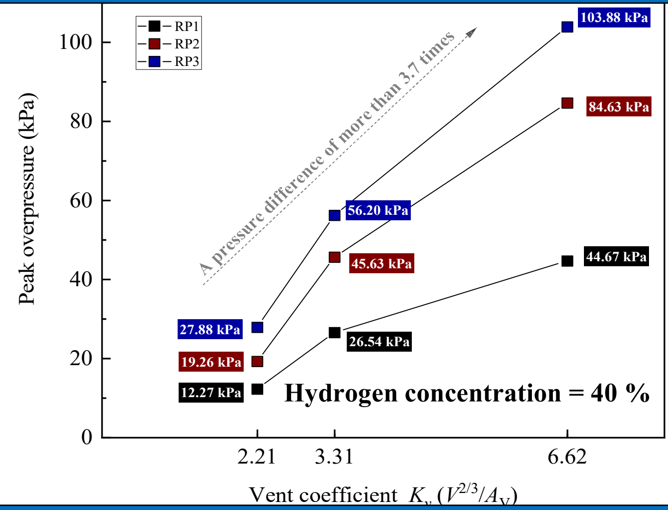
## 1.3 Previous research and purpose of this study

**View of experimental structure**




**Vent conditions**


**Results of the peak overpressure according to the vent coefficient (Kv)**



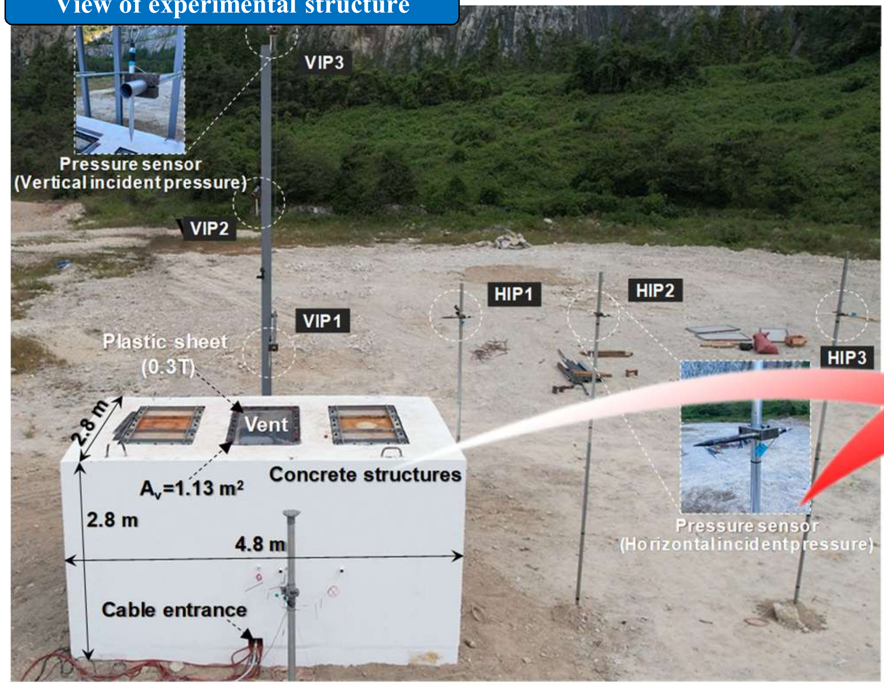

**Airtight condition & hydrogen concentration 20%**


❖ The previous research analyzed and confirmed **the damping effect of peak overpressure** depending on **the size of the vent** as an option to minimize **the impact of deflagration of hydrogen-air gas mixtures in an enclosure on people and buildings**.

# 2. Methods and materials

## 2.1 Experimental structures and measuring instruments

**View of experimental structure**




**Overview of the experiment**

- Experiment place: Army Corps of Engineers
- Experiment structure: L:4.8m x W:2.8m x H:2.8m
- Manufactured as a full-scale concrete structure with an internal volume of 20.3m$^3$
- Vent size: L:1.5m x W:0.75m
- Vent design for opening and closing



**Overview of experimental structure**

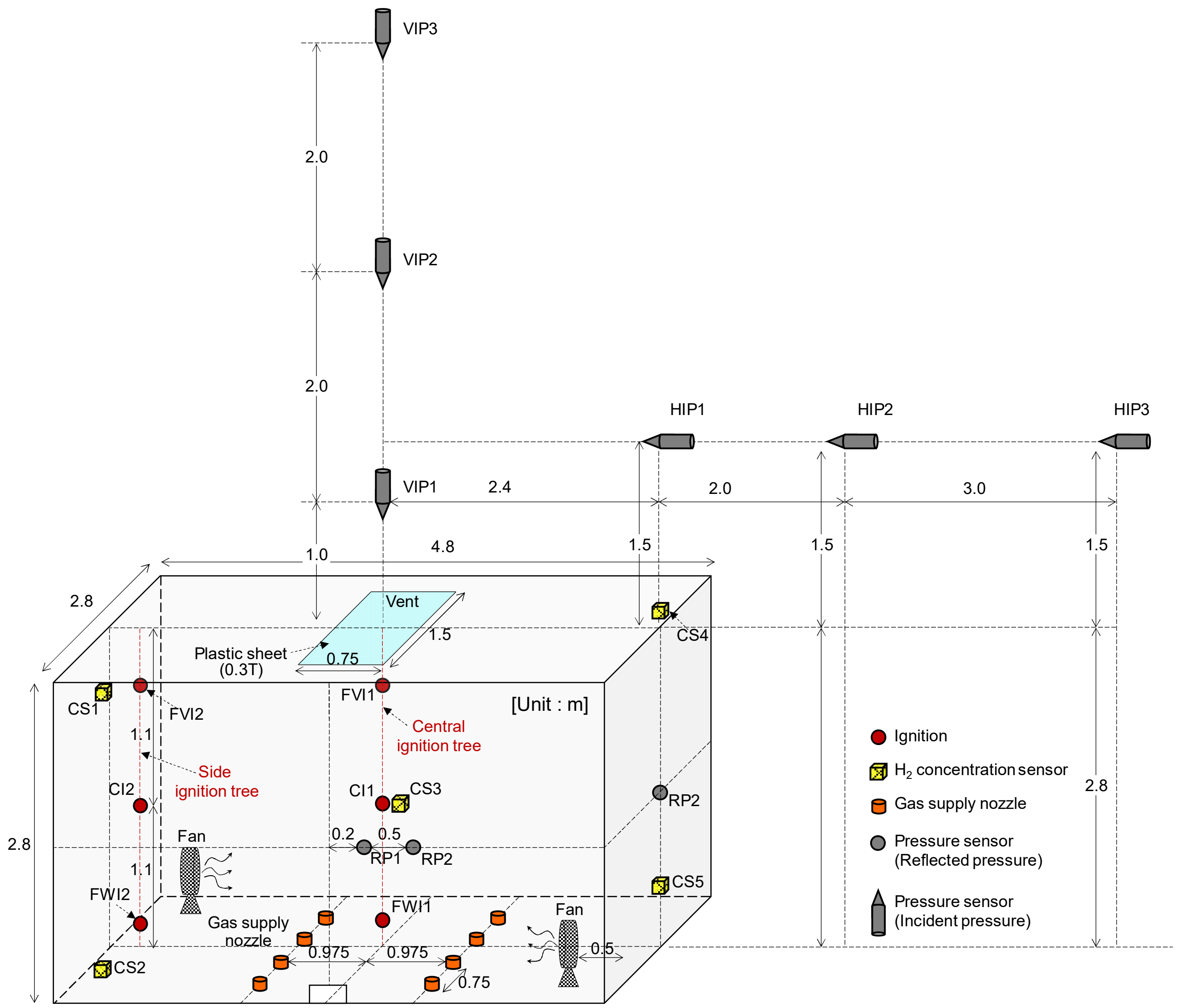
| Type | Structures | | | | | | Roof vent | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Concrete structures | Dimensions (m) | | | Thickness (m) | Volume (m$^3$) | | Dimensions (m) | | Area A (m$^2$) | Coefficient $K_V$ ($V^{2/3}/A_V$) |
| | L | W | H | W | Internal | External | L | H | | |
| | 4.8 | 2.8 | 2.8 | 0.3 | 20.33 | 37.63 | 0.75 | 1.5 | 1.13 | 6.62 |

❖ This study conducted an experiment to identify the effect of vented deflagration depending on the ignition location in a concrete structure filled with hydrogen-air gas mixtures in the enclosure.

# 2. Methods and materials

## 2.1 Experimental structures and measuring instruments

**Overview of experimental structure**




**Measurement related sensors and devices**

# 2. Methods and materials



## 2.2 Experiment conditions and method

**Experiment conditions**

| Test no. | Vent condition | Vent coefficient | Ignition location | | Concentration of hydrogen |
|---|---|---|---|---|---|
| 1 | $A_v$ = 1.13 m$^2$ | $K_V$ = 6.62 | Central ignition tree | Front-vent ignition 1 | 29.0 % |
| 2 | | | | Central ignition 1 | |
| 3 | | | | Floor-wall ignition 1 | |
| 4 | | | Side ignition tree | Front-vent ignition 2 | |
| 5 | | | | Central ignition 2 | |
| 6 | | | | Floor-wall ignition 2 | |

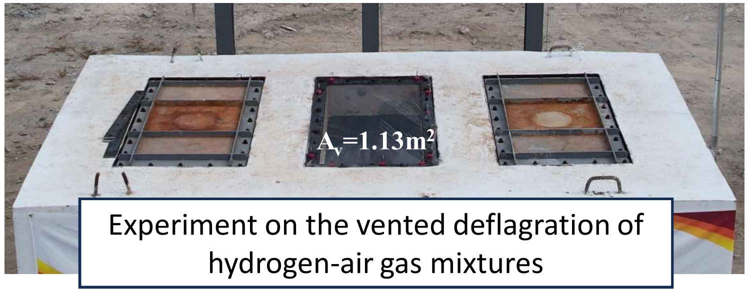
**Vent condition**

- **NFPA 68 (2013) & KFS 720 (1998)**

$$A_{v0} = A_s \frac{\left[1 - \left(\frac{P_{red}+1}{P_{max}+1}\right)^{1/\gamma b}\right]}{\left[\left(\frac{P_{red}+1}{P_{max}+1}\right)^{1/\gamma b} - \delta\right]} \frac{S_u \rho_u}{G_u} \frac{\lambda}{C_d}$$

Where $A_{v0}$– the vent area calculated, m²; $A_s$– the enclosure internal surface area, m²; $P_{red}$– the maximum pressure developed in a vented enclosure during a vented deflagration, bar-g; $S_u$– fundamental burning velocity of gas-air mixture, m/s; $\rho_u$– mass density of unburned gas-air mixture, kg/m³; $\lambda$– ratio of gas-air mixture burning velocity; $G_u$– unburned gas-air mixture sonic flow mass flux, kg/m²-s; $C_d$– vent flow discharge coefficient; $P_{max}$– the maximum pressure, bar-g; $\gamma b$– ratio enclosure pressure prior to ignition, bar-g.

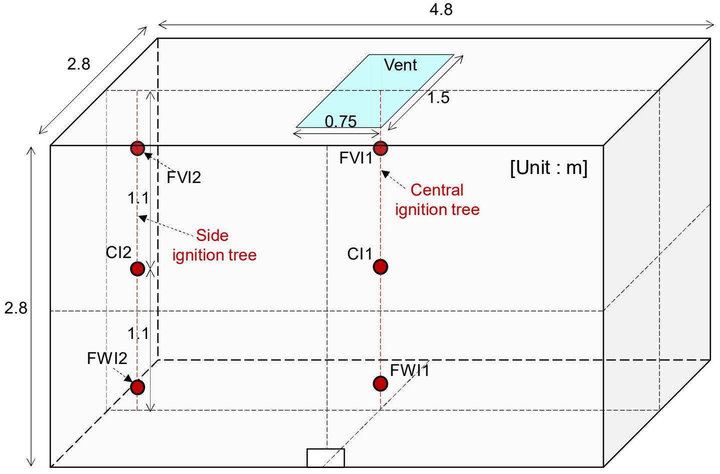
KFS720, 1998. Standard on venting of deflagrations code.
NFPA68, 2013. Standard on explosion protection by deflagration venting code.




Experiment on the vented deflagration of hydrogen-air gas mixtures

**Ignition location conditions**

- Central ignition tree (Front-vent ignition1, Central ignition1, Floor-wall ignition1)
- Side ignition tree (Front-vent ignition2, Central ignition2, Floor-wall ignition2)



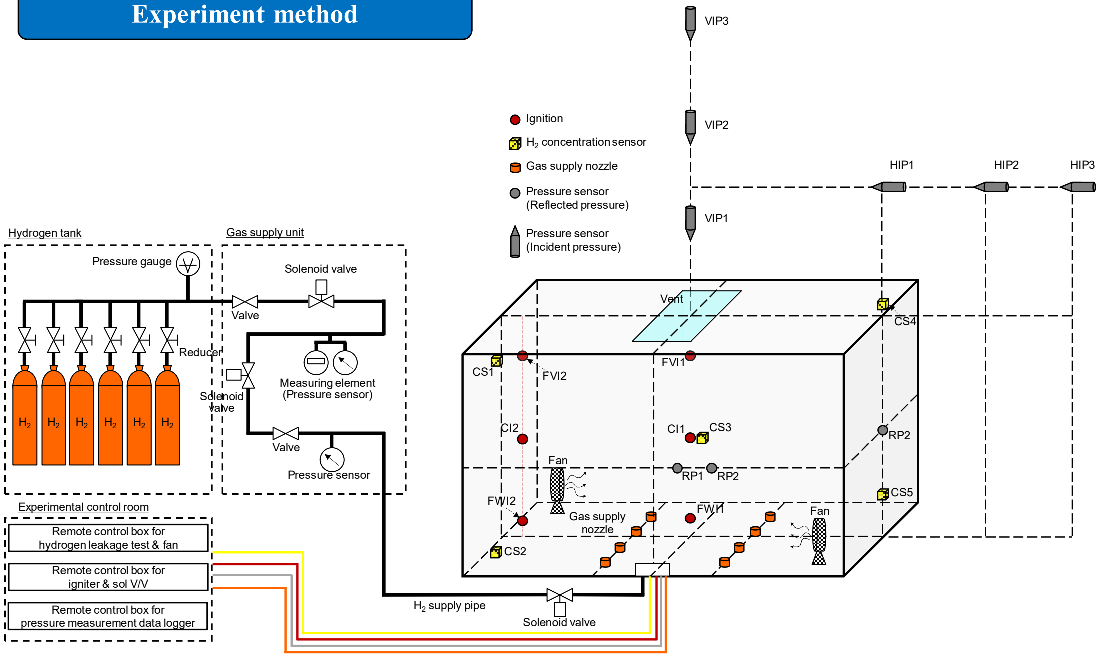

**Hydrogen concentration conditions**

We set the hydrogen concentration at 29.0 %, corresponding to an equivalence ratio (Ø) of 1.0, in which the hydrogen-air combustion reaction proceeds efficiently

# 2. Methods and materials

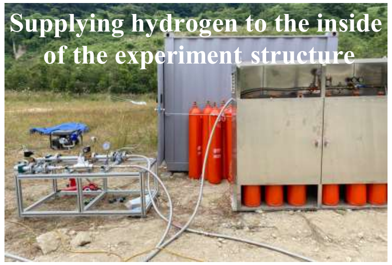
## 2.2 Experiment conditions and method

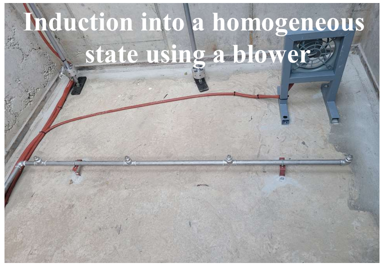
### Experiment method



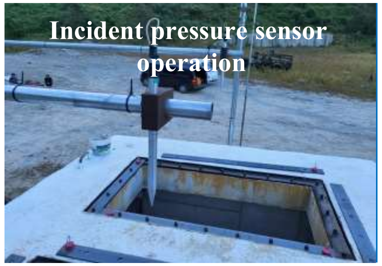

| No. | Contents |
|---|---|
| 1 | Airtight condition using vinyl sheet |
| 2 | Supply hydrogen to the inside of the experiment structure |
| 3 | Stop supplying hydrogen when the hydrogen reaches ±3% of the desired range |
| 4 | Use a blower to induce good mixing of hydrogen and air in the space |
| 5 | When the hydrogen concentration in the space stabilizes, the data logger and therma l imaging camera are activated |
| 6 | Ignite the mixed gas; explosion occurs immediately after ignition |
| 7 | Measure the incident pressure and reflected pressure in units of time using a pressure sensor connected to the data logger |

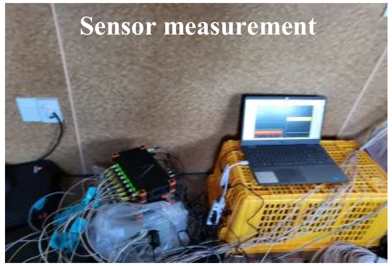




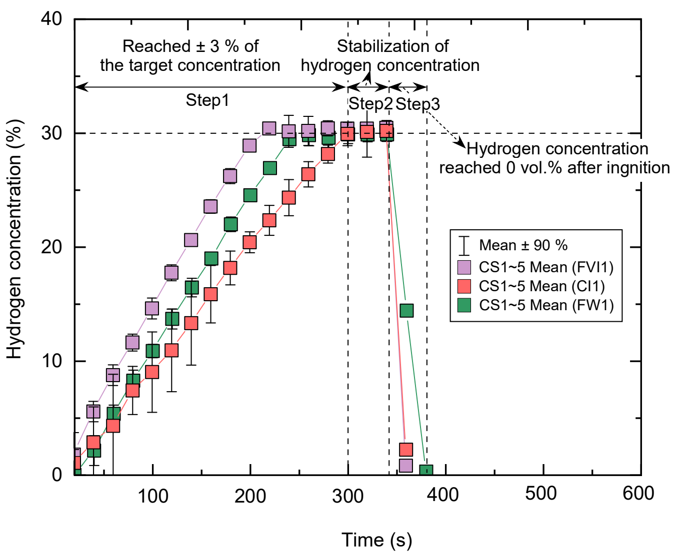


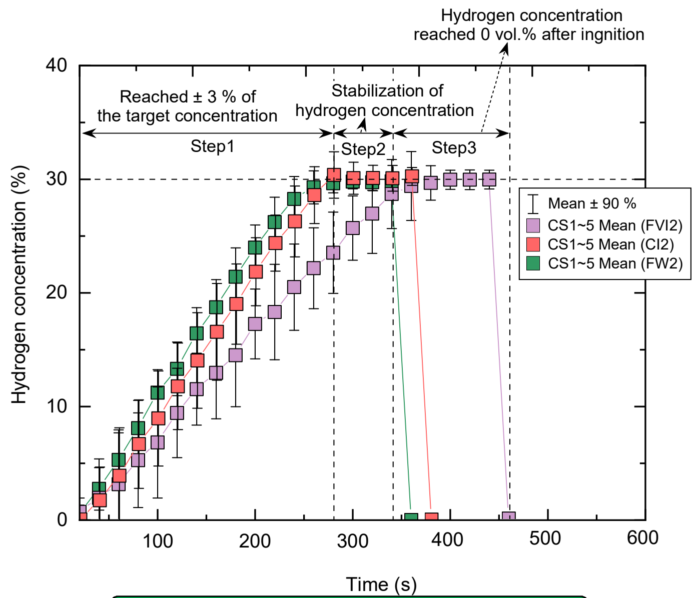
# 3. Results and discussion



## 3.1 Hydrogen concentration histories of the roof vented deflagrations

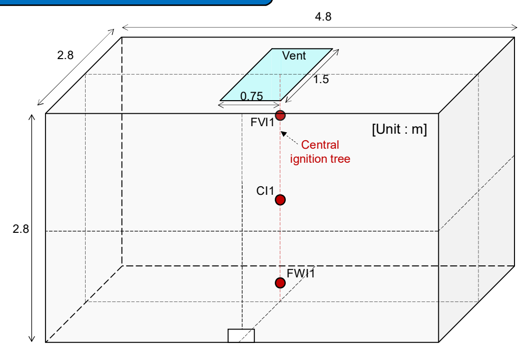



Central ignition tree

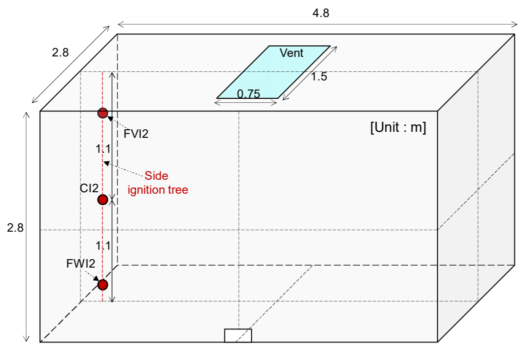



Side ignition tree

Ignition location conditions




**Central ignition tree**
**(Front-vent ignition1, Central ignition1, Floor-wall ignition1)**

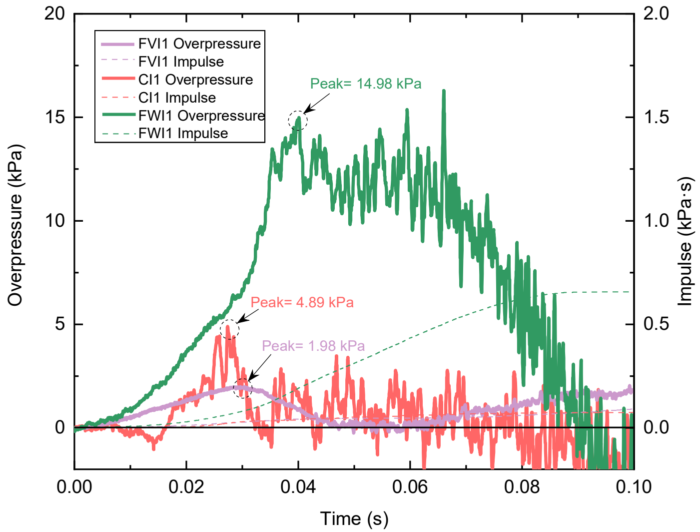



**Side ignition tree**
**(Front-vent ignition2, Central ignition2, Floor-wall ignition2)**

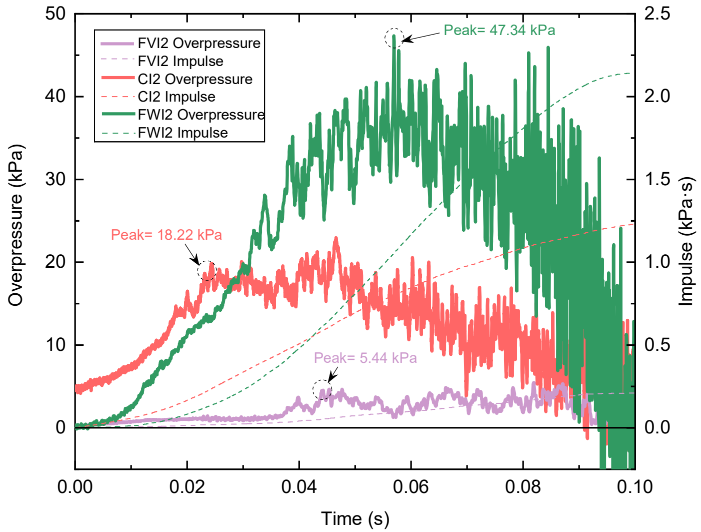
# 3. Results and discussion



## 3.2 Overpressure recordings in roof vent deflagration (Reflected pressure, RP)

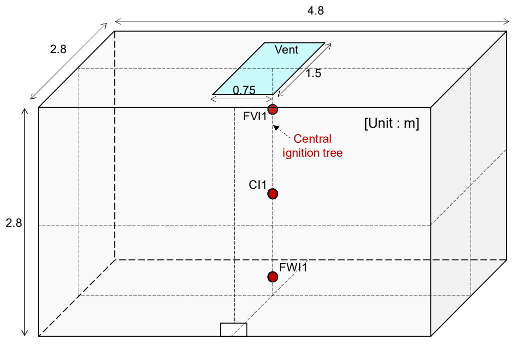



Central ignition tree

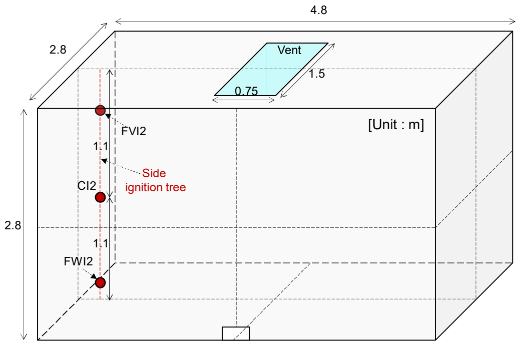



Side ignition tree

**Ignition location conditions**




**Central ignition tree**
**(Front-vent ignition1, Central ignition1, Floor-wall ignition1)**



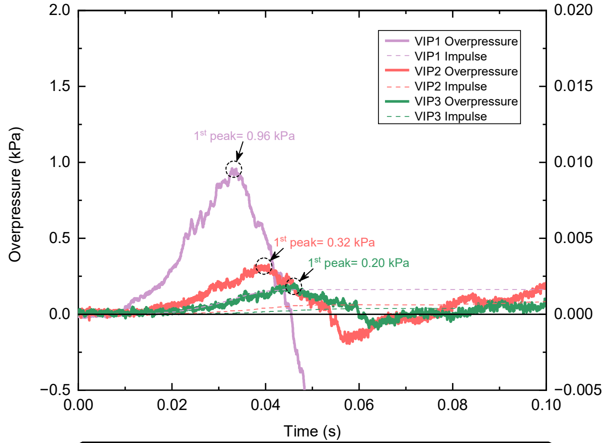

**Side ignition tree**
**(Front-vent ignition2, Central ignition2, Floor-wall ignition2)**

# 3. Results and discussion

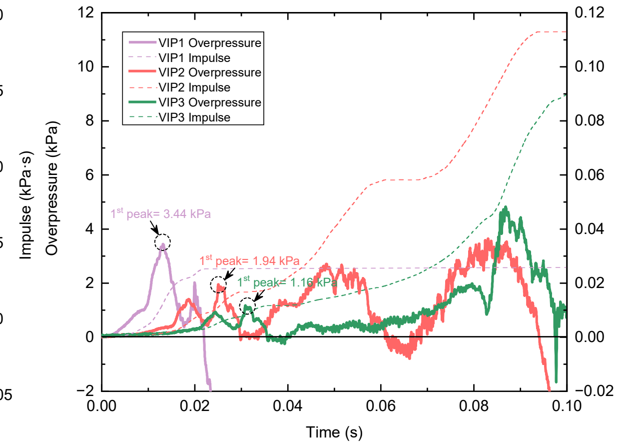


## 3.2 Overpressure recordings in roof vent deflagration (Vertical incident pressure, VIP)

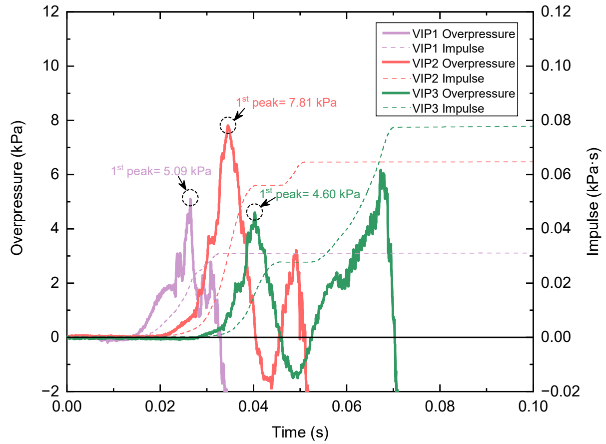
**Central ignition tree**




**Front-vent ignition 1**

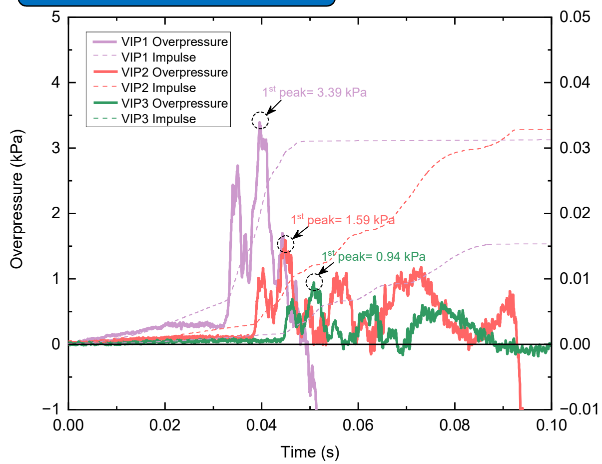



**Center ignition 1**

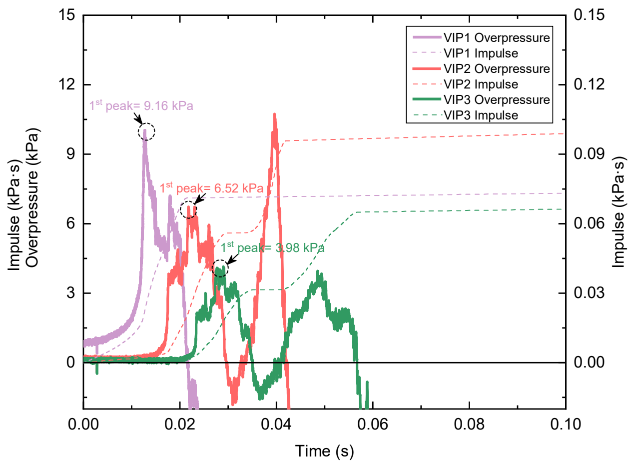



**Floor-wall ignition 1**

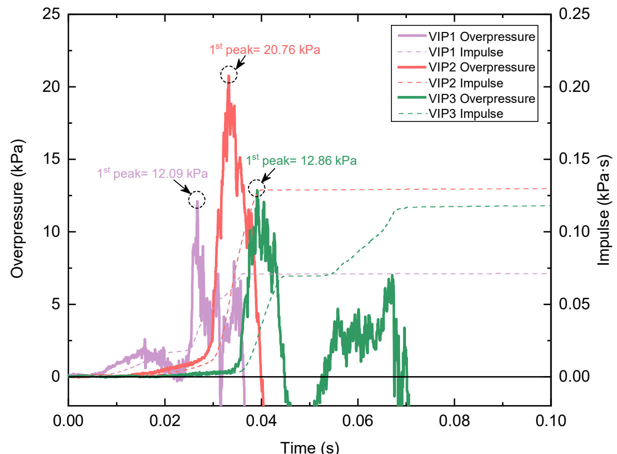
**Side ignition tree**




**Front-vent ignition 2**




**Center ignition 2**



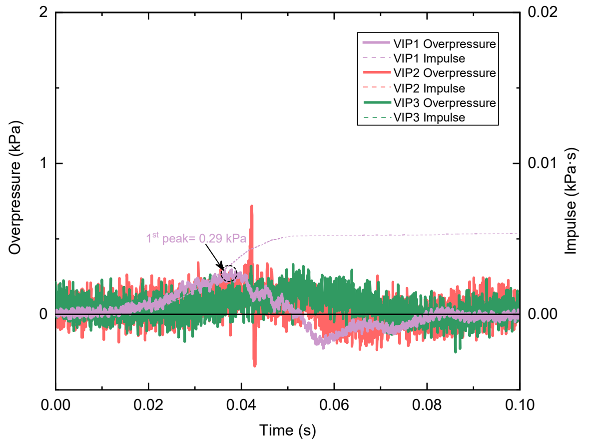

**Floor-wall ignition 2**

# 3. Results and discussion

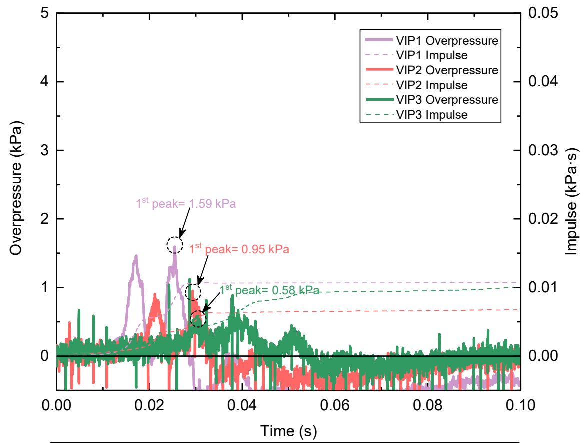


## 3.2 Overpressure recordings in roof vent deflagration (Horizontal incident pressure, HIP)

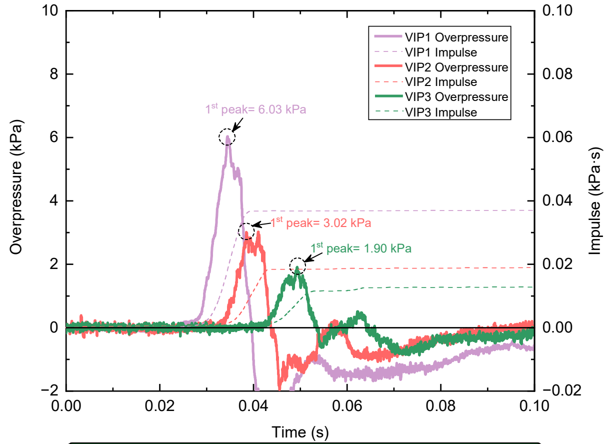
**Central ignition tree**




**Front-vent ignition 1**

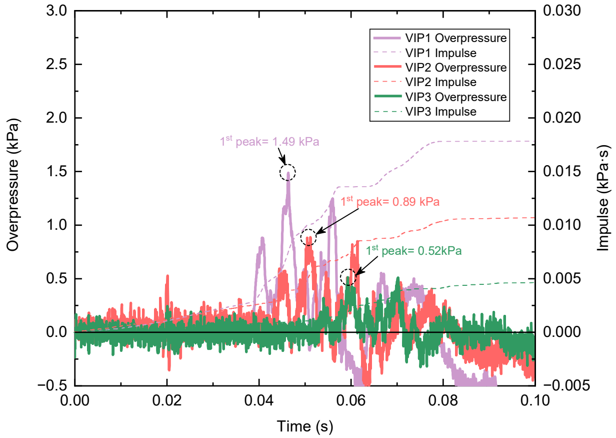



**Center ignition 1**

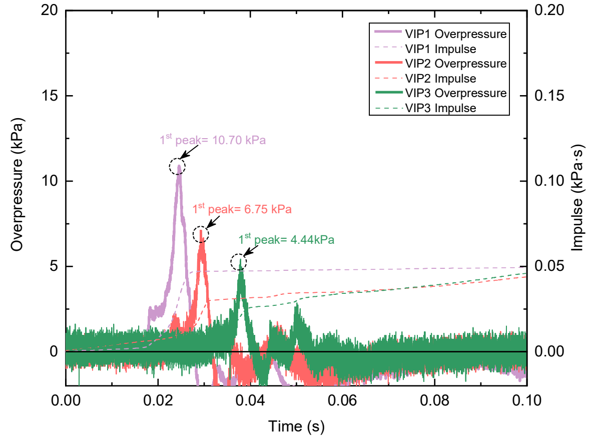



**Floor-wall ignition 1**

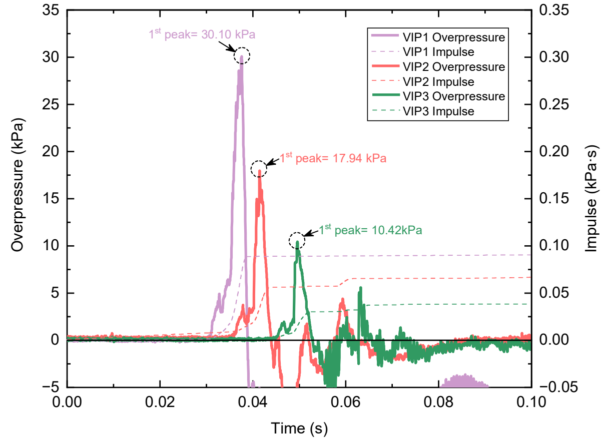
**Side ignition tree**




**Front-vent ignition 2**




**Center ignition 2**

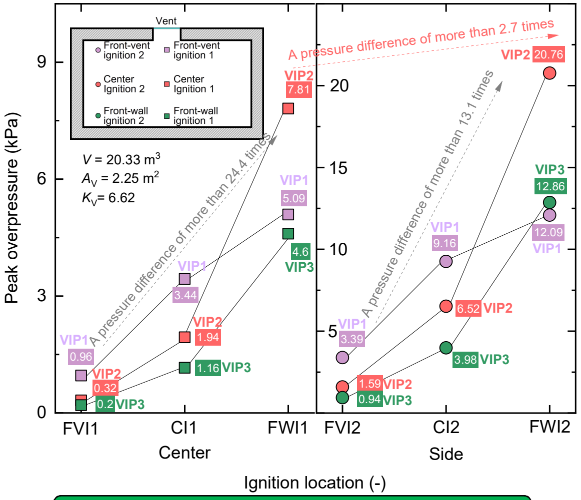



**Floor-wall ignition 2**

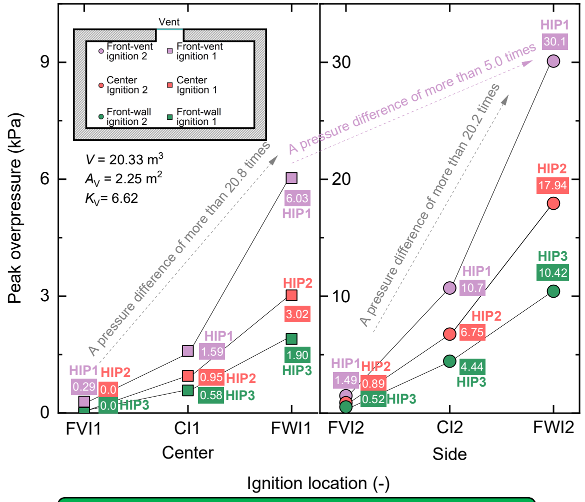
# 3. Results and discussion



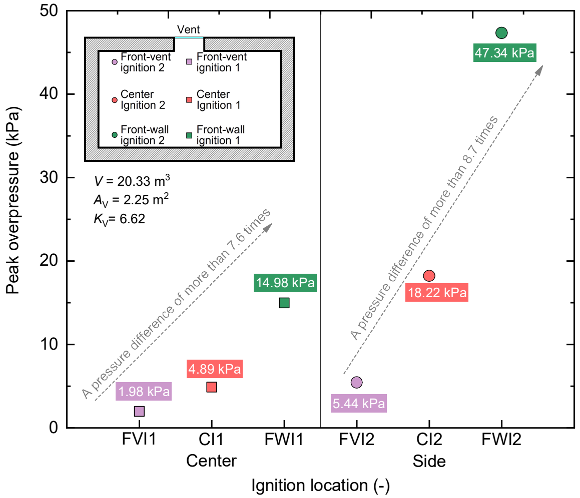
## 3.3 Effect of ignition location on peak overpressure value




Vertical incident pressure



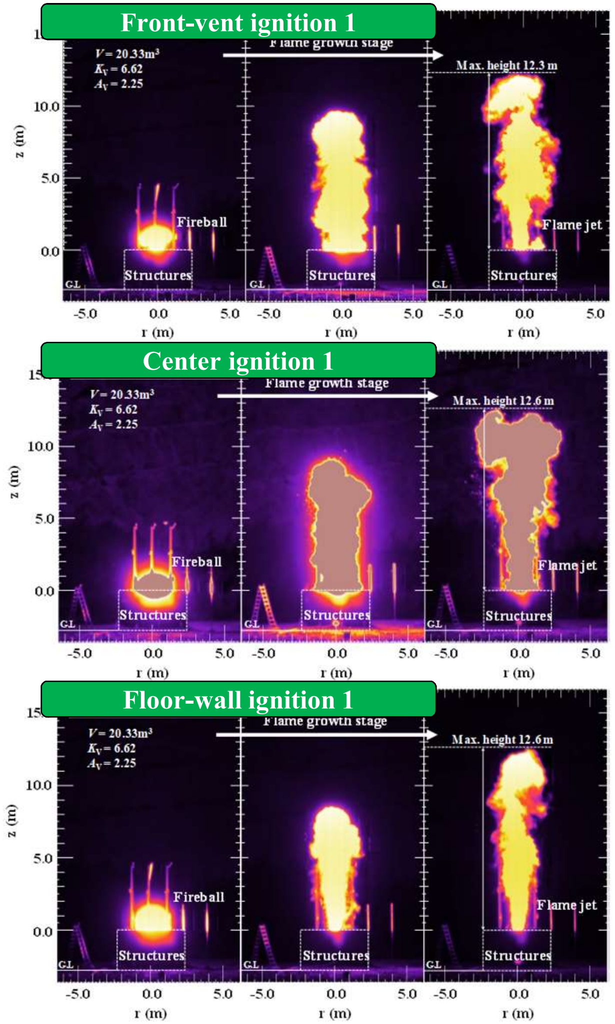

Horizontal incident pressure

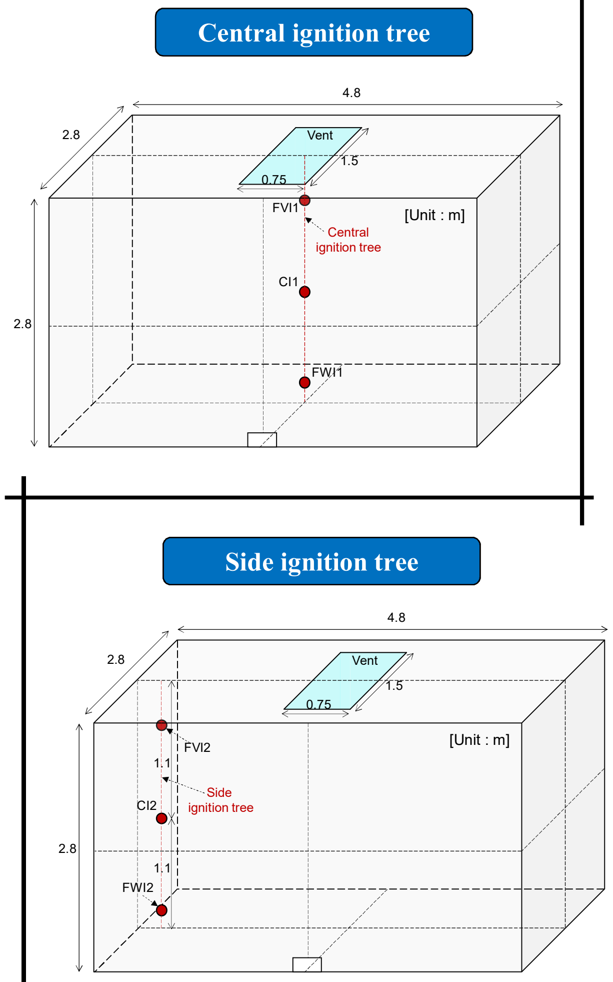


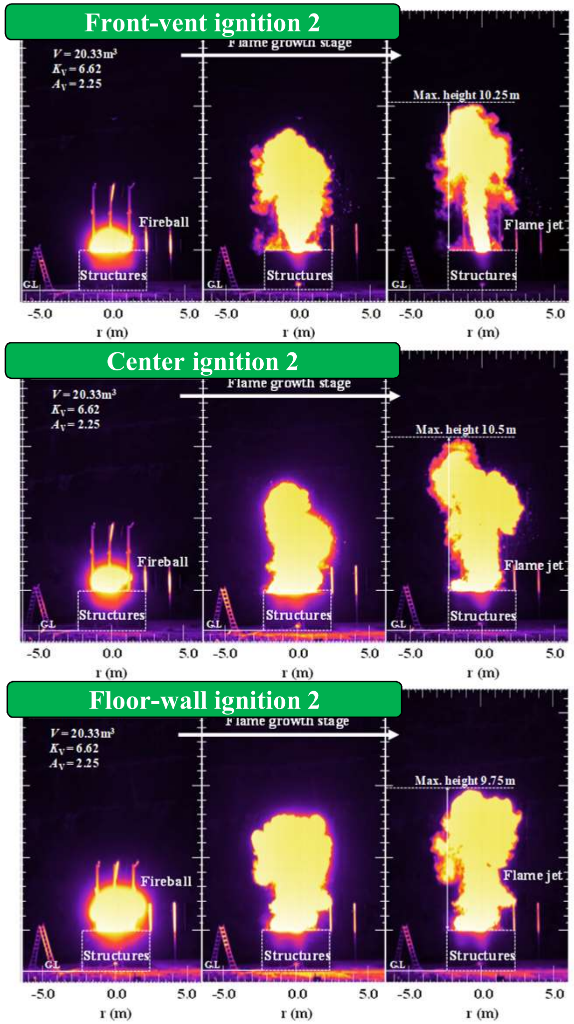

Reflected pressure

# 3. Results and discussion

## 3.4 Effect of ignition location on external flame behavior



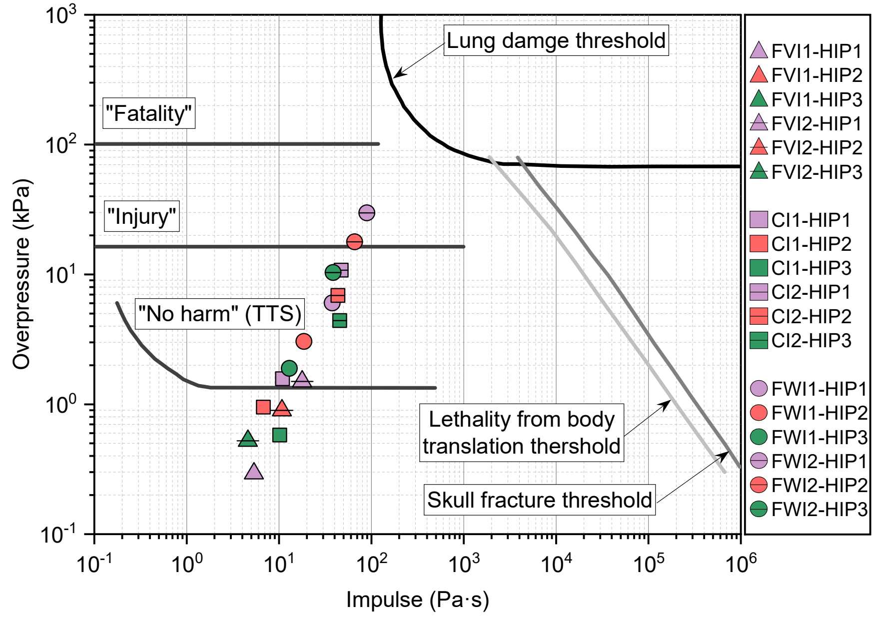



# 3. Results and discussion



## 3.5 Damaging effect on humans from vent explosions

**Overpressure-impulse thresholds of harm criteria for humans**




**Effects of blast waves on human health**

| Incident pressure (kPa) | Damage level |
|---|---|
| 13.8 | Eardrum rupture threshold |
| 16.5 | 1 % eardrum rupture probability |
| 23 | 1 % eardrum rupture |
| 25 ~ 35 | 1 % fatality probability |
| 34.5 ~ 48.3 | 50 % eardrum rupture probability |
| 35 | 15 % fatality probability |
| 50 ~ 100 | 50 % fatality probability |

# 4. Conclusions



In this study, we conducted experiments to determine the effects of vent explosions according to the location of the ignition in a cuboid concrete structure (20.33 $mm^3$) with a vent (1.13 $m^2$) on its roof, filled with a hydrogen-air mixture (29.0 Vol.%).

The main conclusions are summarized as follows.

1. With the increasing distance of the ignition source from the vent, the impact on overpressure and flame behavior increases, resulting in up to 24.4 times greater incident pressure values and up to 8.7 times greater reflected pressure values.

2. When exploring the behavior of the generated external flame, we observed that the shape of the formed flame differed according to the ignition location. In particular, the central ignition tree formed a flame with a long cylindrical column shape, whereas the side ignition tree formed a flame with a wide mushroom-cloud shape.

3. We predicted that distant ignition (FWI2, side ignition tree) might result in "Injury" level damage to humans (1% fatality probability) at a distance of 2.4 m away from the vent (HIP1), whereas almost no damage will occur at a distance of 7.4 m or more from the vent.

The results of this study are used as basic data for presenting design guidelines for explosion vents in underground spaces.

# Thank you for your attention !!

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