The 6th International Conference on Construction Engineering and Project Management (ICCEPM 2015)
Oct. 11 (Sun) ~ 14 (Wed) 2015 • Paradise Hotel Busan • Busan, Korea
www.iccepm2015.org

Study on the Safe Evacuation Management in a Power Supply Disturbed Emergency

Nobuyuki Suzuki[1], Tsubasa OHASHI[2] and James R WHORLOW[3]

Abstract: For construction projects it is imperative that site management gives the highest priority to planning safe site evacuation for all foreseeable emergencies, including earthquakes and typhoons which are often experienced in Japan. This is especially important and even more critical for high risk projects involving underground works, such as Tunneling & Pneumatic Caissons. Based on the safety regulation of underground works, a back-up power supply system must be provided during the construction period at all times. Often, fluorescent lamps with re-chargeable batteries are provided for infrequent emergency cases, however these have a questionable useable life span and thus need careful maintenance and periodical replacement. In this paper we focused on using the phosphorescence materials to indicate the evacuation direction. As a result, it was confirmed that the phosphorescence materials were considered useful in reducing panic and facilitating a controlled evacuation in the event of a total black-out due to power failure.

Keywords: phosphorescence materials, Evacuation Management, underground works, power supply disturbed emergency

I. BACKGROUND

In 1995 a huge earthquake struck the western Japan city of Kobe area and impacted the lives of over 6,000 people [1]. One key factor in this event was that the Mayor in the Kobe City regional office was not able to call in the assistance of the Self-Defense Forces. Subsequent investigations[2] confirmed local communications had been cut off by a failure in the power supply, and back-up generators were inoperable due to overturned water tanks. This serves as just one example that demonstrates it is almost impossible to predict every outcome and possible scenario that may transpire during an emergency.

For construction projects it is imperative that site management gives the highest priority to planning safe site evacuation for all foreseeable emergencies, including earthquakes and typhoons which are often experienced in Japan. This is especially important and even more critical for high risk projects involving underground works, such as Tunneling & Pneumatic Caissons.

Based on the safety regulation of underground works, a back-up power supply system must be provided during the construction period at all times. Often, fluorescent lamps with re-chargeable batteries are provided for infrequent emergency cases, however these have a questionable useable life span and thus need careful maintenance and periodical replacement.

One consideration may be the use of phosphorescence materials which can glow for 8 (or more) hours after sunset and could easily indicate evacuation pathways. There are four types of phosphorescence materials classified by the Japanese Industrial Standard, which are JA, JB, JC and JD classes respectively. The JD class provides the highest brightness, however the cost and lifespan is less attractive than other classes, especially if intended use is in wet conditions as would be likely at underground work sites.

II. PURPOSE

We, as site managers, are obliged to provide the safest possible evacuation system at reasonable cost that will facilitate all foreseeable risks and/or unexpected emergency events. In almost all underground areas (such as railway underground station concourses) evacuation signs have been provided, and these have included phosphorescence products since guidance was included in the review of the Fire Service Act in Japan in 2006. In the Construction industry however, many workers and even site managers are not familiar with phosphorescence materials and their potential uses.

The purpose of this study is that we have set out to confirm the usability, applicability, and general suitability of phosphorescence materials as a highly effective medium for providing evacuation guidance in the event of a total power supply failure. Prior to undertaking trials at three construction sites, we pre-verified the suitability of potential materials/products at our university campus.

III. PHOSPHORESCENCE MATERIALS

A. Outlines of Phosphorescence Materials

Phosphorescence Materials absorb the light energy through exposure to sunlight or other bright light sources. In particular they are sensitive to ultraviolet rays.

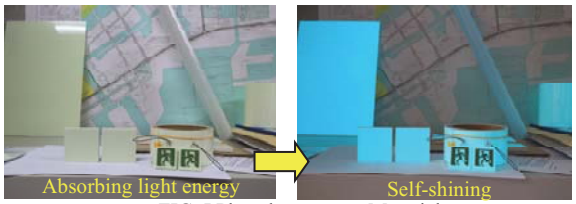

FIG. I Phosphorescence Materials

[1] PhD, Professor of Toyo University, 2100 Kujirai, Kawagoe city, Saitama Prefecture, Japan, suzuki060@toyo.jp (*Corresponding Author)
[2] Student of Toyo Universirty,2100 Kujirai, Kawagoe city, Saitama Prefecture, Japan, kc1100479@toyo.jp
[3] ACGI, BSc(Eng), CEng, MICE, CQP, MCQI, MCMI, Head of QA/QC, MMC Gamuda KVMRT (T) SDN BHD, Level 7 Corporate Building (Block E) Pusat Komersial Southgate, No2 Jalan Dua, off Jalan Chan Sow Lin, 55200 Kuala Lumpur, Malaysia, JamesWhorlow@kvmrt-ug.com.my

During darkness, or when all external light sources are turned off, phosphorescent materials release light energy gradually in the form of a glow that may last as long as 8 hours or more. The durability, and any degradation in performance from repeatable usage is dependent on the Zinc sulfide or strontium aluminate content.

Following recent terror attacks and other disasters worldwide, the need to provide effective and efficient guidance during emergencies has again become a key topic. This is evidenced by the transportation department of Yokohama City and Tokyo Metropolis instruction to all railway management organizations to install explicit emergency signage which may include materials that are phosphorescent.

In the Japanese industrial standard, there are four types of phosphorescent materials specified, namely: JA class, JB class, JC class and JD class[3]. The major differentiating factor between them being the brightness after dark (TABLE I for your reference).

TABLE I
Classification by Japanese Industrial Standard

	2min.	10min.	20min.	30min.	60min.
JA	210	50	24	15	7
JB	440	105	50	31	15
JC	880	210	100	62	30
JD	1760	420	200	124	60

Condition of lighting is 20min with 200 lux.
Unit is mcd/m^2 (millicandera / m^2).

B. Difference of Illuminance and Brightness

Basically all objects receive incident light from outside and release light energy. Therefore there are two basic evaluation techniques [4] as shown below;

1) Illuminance

The luminous quantity is evaluated as the total incident light flux per unit area shown as below;

$$Ev=d\Phi v / dA$$

Unit is lx.

dΦv : incident light flux
dA : unit area

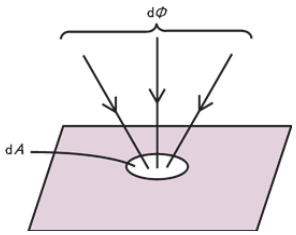

FIG. II Illuminance

2) Brightness

The brightness is evaluated as the strength of light source to observer.

$Lv=d^2\Phi v / (d\Omega \cdot dA \cdot \cos\theta)$
Unit is cd/m^2 (candera/m^2).

$d^2\Phi v$: emission beam through the point with angle dΩ
dA: area of the beam point
θ：angle between beam and area

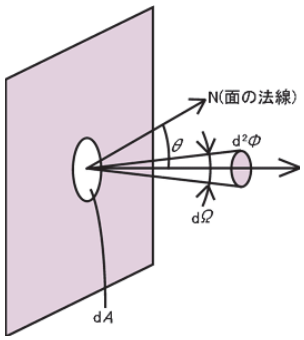

FIG. III Brightness

VI. APPLICATION AND PREVIOUS STUDY

A. Products and Application

Many products utilize phosphorescent materials including those for safe evacuation signs where typically the higher brightness materials have been adopted. These have generally been installed for emergency guidance in the areas of poor power supply or low population.

The Japanese market is buoyant with ideas and fast expanding the products available; such as tape style, flexible plastic plates, acrylic plates, glazing on ceramics, and many more. Coloring is also very flexible and can be suited to almost any application, though for evacuation; blue, green, orange, and yellow are typical and most common.

Most noticeable previous applications of phosphorescence materials include: wristwatches, key holders, ladies nails, and many others that attract us and draw us in on a daily basis.


FIG. IV phosphorescence Products (Tape and Evacuation Sign)


FIG. V Phosphorescence Material on wristwatch

B. Previous Study in Civil Engineering Field

1) A development of non-power supply equipment using Phosphoresce material [5]
Evacuation assisting materials without power supply, such as directions and/or equipment in the case of power supply interruption.
2) A study on visibility of evacuation signs made of phosphoresce materials [6]
The study considered the reduction of visibility during a natural disaster which results in a total power black-out. Conclusions confirmed the visibility of phosphoresce materials used in evacuation signs were acceptable to both workers and site management.
3) A study on characteristics of evacuation with phosphoresce materials under night vision [7].
The psychological characteristics of workers were studied whilst using their night vision to locate emergency exits in a damaged building.

Hence, there are not many submissions dealing with the usage of phosphorescent materials within the construction

industry that have been submitted to the JSCE (Japan Society of Civil Engineer's) to date. The adoption of phosphorescent materials, especially to facilitate safe evacuation during power failures, has significant potential within the Civil Engineering Industry.

V. EVACUATION EXPERIMENTATION

A. Campus Experiments

Initially we experimented with several phosphorescent materials on our campus to evaluate and compare visibility /effectiveness. We present the data and dimmer curves obtained from our studies (see TABLE II and FIG.VI) for comparison of functions & performance. To assist in material efficiency evaluations and comparisons, we also tracked and recorded the initial afterglow transition up to 60 min (see FIG.VII).

Early results very quickly indicated that the brightness of the JD class Tape and Acrylic Resin Plate were more durable with afterglow beyond a six hour elapsed time. It was also evident from the trials that the most visible material was JD class as defined in JIS (Japan Industrial Standard). Typically however, evacuation signs made of JD class are usually fixed on large commercial facilities with more than 10 years exposure to the public. This raises the concern on cost effectiveness if such JD signage is to be reproduced over the much shorter periods needed for construction sites where the effectiveness of JA class may be adequate and should be taken into account.

The experiments were unable to distinguish effectiveness comparisons as the brightness of all the materials were recorded to be just 39-199 mcd/m^2 within one hour of test commencement. We therefore concluded that even JA class material may be suitable for emergency evacuation purposes. For enhanced practical study and further material evaluations, we then installed our phosphorescent materials at three different operational construction sites.

B. Work Sites Experiments

JA class phosphorescent materials were initially installed at/near the exit locations under normal conditions where it was anticipated they would provide 400-600 lux light for minimum 30 minutes. On darkening the site, it was noted that the installed phosphorescent materials were almost invisible and did not indicate the exit location. This was confirmed in discussions/interviews with workers as well as site managers. Further trials then focused on using the phosphorescence materials to indicate the direction to the emergency exits. Results proved positive and debrief discussions confirmed the phosphorescence as useful in reducing panic and facilitating a controlled evacuation in the event of a total black-out due to power failure.

JA class phosphorescence materials were then installed at 3 active working construction sites to verify the efficiencies and/or the current problems to be addressed.

a) Sequence of Experiment

① Measuring illuminances at corners, gates, evacuation ways, and potentially dangerous locations.
② Installing phosphorescence materials at dangerous points, corners, evacuation ways
③ Accumulating light data for 20 min. approx.
④Switching off the power supply for darkening
⑤ Verification of visibilities at the immediately blackout, 10 to 60 min. later with 10 min. interval
⑥ Hearing from site workers and managers

TABLE II Photometry Records of Phosphorescence Materials

Time Elapsed (min)	Type JA Tape	Type JD Tape	JA : Acrylic Resin Plate	JD : Acrylic Resin Plate	JA Ceramic Tile
0	999	999	999	999	999
0	999	999	999	999	999
5	870	999	835	999	670
10	688	859	617	872	290
15	158	520	303	672	209
20	119	378	239	551	168
30	79	243	132	429	108
40	52	174	118	314	80
50	42	130	92	238	62
60	39	118	77	199	57
90	20	70	49	120	30
120	19	47	34	84	21
150	17	37	27	63	16
180	9	29	22	52	13
210	8	23	19	47	10
240	7	21	16	38	9
270	5	19	14	30	8
300	4	16	12	28	8
360	4	12	10	20	8
420	2	11	8	17	4
480	2	9	7	15	4

Unit is mcd/m2 (millicandera / m2)

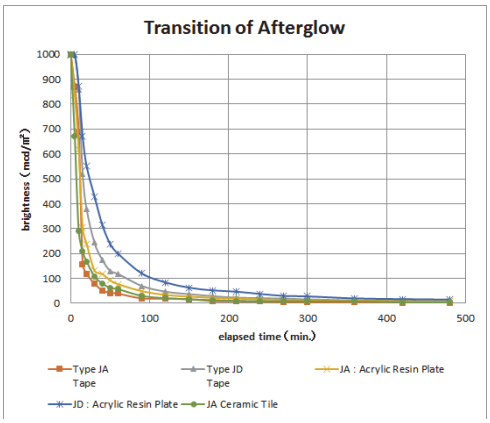

FIG.VI Transition of Afterglow (8 hours)

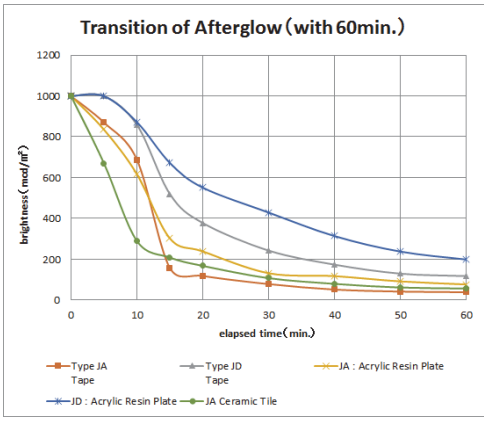

FIG. VII Transition of Afterglow (with 60min.)

b) Actual Site Experiment Details

1) 5 stories Reinforced Concrete Building with total 6,800m^2 flor area

- Evacuation experiment carried out on ground floor as this had no widows to provide light whilst under construction phase.

- Used Materials & cost
  - i. Phosphorescence Tape
    At the door frame and floor footing
    · 2000㎜×50.8㎜ (2nos.)
    · 1440㎜×50.8㎜ (1no.)
    · 100㎜×50.8㎜ (7nos.)
  - ii. Total material cost
    · 4 inch. Tape 3.07m ≒ US$83-/1 exit
- Major Comments and Opinions
  ·Visibility and colour were acceptable
  ·Peaceful of mind was felt

FIG. VIII Phosphorescence Materials Fixed on Ground Floor and Switched off Power Supply

2) 2,000mm dia. Shield Tunneling for Water Supply Pipes

- Evacuation experiment was carried out inside the tunnel where emergency fluorescent lamps and batteries are equipped at all times.
- Phosphorescent tapes and plastic covers were fixed as below;
- Used Materials & cost
  - i. Phosphorescence Materials
    · 50.8mm ×100mm (28nos.)
    · Fluorescent lamp cover 1,200mm (4nos.)
  - ii. Total Material Cost
    · 4 inch. Tape 1,400mm ≒ US$38-
    · 4 Fluorescent Lamp Covers ≒ US$55-
    · Total Cost ≒ US$93-/5m
- Major Comments and Opinions
  · Visibility was acceptable
  · Fixing locations would need to be changed to suit progress of work. Therefore it may cost more than emergency battery type.

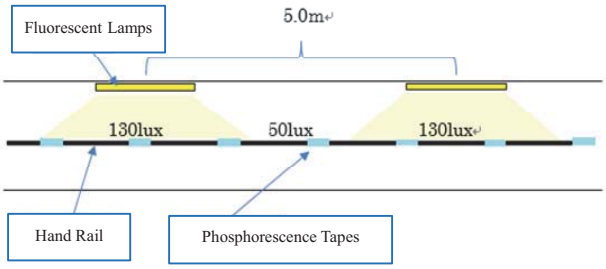

FIG. IX Phosphorescence Tapes Arrangement

- Major Comments and Opinions
  · Visibility was acceptable
  · Fixing locations would need to be changed to suit progress of work. Therefore it may cost more than emergency battery type.

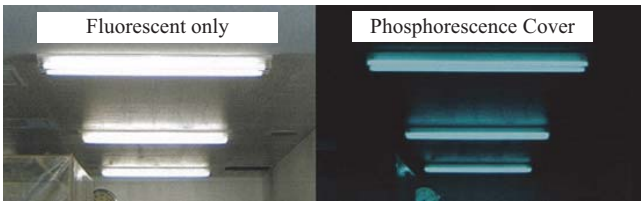

FIG. X Fluorescent Lamp Cover

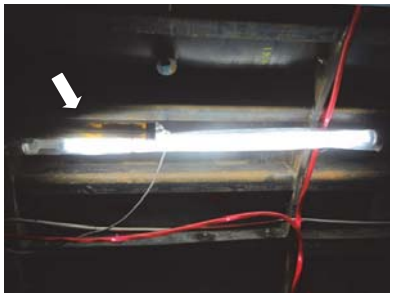

FIG. XI Emergency Rechargeable Buttery

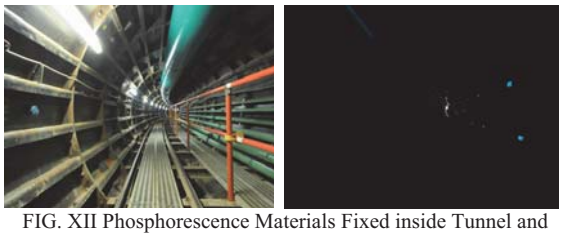

FIG. XII Phosphorescence Materials Fixed inside Tunnel and Switch off Power Supply (right)

3) Underground works of pneumatic caisson for a water diversion pump station

- Evacuation experiment was carried out inside the underground area where emergency fluorescent lamps and batteries are equipped at all times.

- Used Materials & cost
  - i. Phosphorescence Materials
    - · 25.4mm ×200mm (16nos.)
    - · 25.4mm ×400mm (8nos.)
    - · 50.8mm ×100mm (8nos.)
    - · 50.8mm Arrow shaped sing (1nos.)
  - ii. Total Material Cost
    - · 4 inch. Tape 2,400mm ≒ US$56-
    - · 4 inch. Arrow Shaped Sign ≒ US$22-
    - · Total Cost ≒ US$78-/1staircase
- Major Comments and Opinions
  - · Visibility was good. All workers were surprised at the brightness which was better than they were expecting. The effectiveness was very high.
  - · Staircase materials are usually sourced from leasing companies, thus agreement would be needed to fix the Phosphorescent materials initially, and some difficulty could also be expected in removing the materials once project is completed.

FIG. XIII Normal condition (left) and Switch off Power Supply near staircase of underground caisson works

c) Maintenance and Running Cost

Once phosphorescent materials have been installed on site, no running costs will be incurred other than maintenance cleaning of the surfaces. The typical monthly electric charging fee for one rechargeable battery is US$55-/50m (US$1-/1m) on the above shield tunneling site. On the face-of- it, this seems one-twentieth of the cost of the phosphorescent materials, though we should keep in mind that this cost does not include the rechargeable battery equipment fee. Further if we are seeking to reduce and minimize risk, then we should look at solutions where the possibility of functional failure is eliminated during any emergency event. In this regards, the benefits of phosphorescent materials are clear.

VI. CONCLUSION

Based on our study we conclude that phosphorescent materials can be used effectively in the construction industry to facilitate emergency evacuation during extreme conditions where even the power supply is compromised and sites are thrown into sudden and total darkness. This, and other potential safety based applications, can reduce possible risk during extreme events to improve site safety emergency preparedness management in the future.

Considering the special features of phosphorescence materials, such as cost, handling, maintenance, and durability, we consider there are other applications where they may be beneficial in improving safety and evacuation management. Such applications may include evacuation guidance plates in remote areas with a poor or regularly interrupted power supply, emergency notices along seashores, and so on.

Furthermore we adopted phosphorescence materials for improving the landscaping as well as seashore safety during dark period on a Virtual Reality Model established. We presented it to regional government offices and received many positive admirations.

One negative factor is that the brightness 30min. after a power cut-out would be reduced from 1,000 to around 80mcd/m^2 which is not adequate to illuminate works areas or exits with just phosphorescence. However, human eyes adjust gradually when exposed to darkness and the associated sensibility dynamic differences have yet to be fully explored for phosphorescence materials. Experimentation on this is a possible area for future study and further enhancing or optimization on the uses of these materials within the Construction Industry.

ACKOWLEDGEMENTS

We would like to express the deepest appreciation to the three site provided for experiments from UDK Construction Inc., TAISEI Corporation and Fudo Tetra Cooperation JV, OBAYAHI Corporation and OHKI Corporation JV, and the phosphorescence materials provided by RYOUKO Co., Ltd and ARISE Corporation.

REFERENCES

[1] The Japan Times ST: Kobe marks anniversary of 1995 earthquake, 2015.01.30, http://st.japantimes.co.jp/news/?p=nm20150130 (Japanese)
[2] National Institute for Land and Infrastructure Management of Ministry of Land, Infrastructure, Transport, Tourism: Investigation Report, 2005.10 (Japanese) http://www.nilim.go.jp/lab/bcg/siryou/tnn/tnn0510pdf/ks051004.pdf
[3] Nippon Signs Association: Phosphorescence Materials, http://signs-nsa.jp/ (Japanese)
[4] HP of KONICA MINORTA : miscellaneous knowledge of color, http://www.konicaminolta.jp/instruments/knowledge/color/part4/12.html
[5] Megumi YOKOISHI : A development of non-power supply equipment using Phosphoresce material, Proceeding of Kanto Branch, Architectural Institute of Japan, 2006
[6] Kazuyuki UEJIMA, Akihiro FUJITA, Hidehiko MURAYAMA, Kaori KANESAKA : A study on visibility of evacuation signs made of phosphoresce material, Proceeding of Hokkaido Branch, Architectural Institute of Japan, 2004
[7] Atsushi SUDO : Study on characteristics of evacuation with phosphoresce materials under night vision, Japan Society of Civil Engineer, Hokkaido Branch, 2013