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An evaluation of seismic recovery curve considering the product stock and damage correlation

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Abstract

After the 2011 Great East Japan Earthquake, industrial companies that store a certain amount of stocks, i.e., their finished products and unfinished products, are increasing in Japan. It is because they want to continue their business and to fulfill responsibility to supply the products to the market. Therefore, an effect of having the stock, whether rational of having how much stock amounts, method and criteria for judging them are needed. The authors proposed a method that can take the consumption of the stock into account recovery curve of production functions. However, there is practically problem; the earthquake damage of manufacturing apparatuses is assuming an independent. Based on above-mentioned circumstances, in this paper, we newly proposed a practical evaluation method which can estimate rations amount of stocks. And its features are; as basic probability theory, assumed the stock amounts to be finite, and adopted impacts of the damage correlation between manufacturing apparatuses. Using the proposed method, recovery curves for an example of virtual manufacturing line including the stocks are estimated, and obtained results such as following. Recovery curve is significantly changed by the stock consumption of the unit time and duration of the stock consumption. In addition, these factors which vary the recovery curves are strongly affected by the damage correlation.

Keywords: Recovery curve, Stock, Damage correlation, System reliability, Earthquake

1. Introduction

The 2011 Great East Japan Earthquake put many manufacturers' production facilities out of operation, leaving them unable to supply their products to the market for a long period of time. In view of the lessons learned from this experience, many manufacturers are thinking of storing a certain amount of raw materials, unfinished products and finished products to prepare for emergencies. Since, however, having a stock is economically disadvantageous mainly because of increases in equipment investment, current assets and various associated expenditures, there is a need for a certain level of rationality in deciding on the amount of stock to be kept. This makes it necessary to establish methods and criteria for decision making. The purpose of this study is to apply post-earthquake recovery curves depicting the post-earthquake recovery process to manufacturing plants and develop a method for determining a rational amount of stock to be kept according to the recovery curve improving effect of stock.

Among previous studies focusing on post-earthquake recovery curves, Shinozuka *et al*. (2004) evaluated recovery curves for water supply systems taking the association with electric power into consideration, and Shizuma *et al*. (2009) evaluated recovery curves for expressways taking the damage correlation into consideration. Doi *et al*. (2013) regarded the water in regulating reservoirs as a stock of resources and evaluated recovery curves for water supply systems for hydroelectric power plants. In their study, however, the amount of water in regulating reservoirs was assumed to be infinite, and the determination of rational amounts of stock was thought of as a subject of further study. Matsumoto and Nakamura (2014) modeled the production process as an organically integrated system of manufacturing apparatuses and proposed a mathematical model for supplying unfinished products and finished products from the stock located in the system. Damage, however, suffered by the manufacturing apparatuses constituting the system was assumed to be independent, an assumption that needs to be addressed for practical application.

Widely used methods of evaluating conditional probability taking correlations into consideration include the method of using multiple integral of joint-probability density functions (e.g. Curnow and Dunnett, 1962; Shanti, 1963) and the Monte Carlo simulation method. Lee and Kiremidjian (2007) presented a risk evaluation method that takes bridge the damage correlation into consideration by using a multiple integral approach, and Nojima (2009) compared the multiple integral method and Monte Carlo simulation with respect to network system reliability.

This study first derives an integration formula that directly incorporates physical quantities associated with intensity of the applied ground motion and the earthquake resistance of the structure of interest from the multiple integral proposed by Curnow and Dunnett (1962) and proposes a recovery curve evaluation method that takes the damage correlation into consideration. Then, by focusing on a production line consisting of a number of manufacturing apparatuses as an example, the recovery curve improving effect of stock and the influence of the damage correlation are discussed.

2. Recovery Curve Considering Stock

2.1 Definition of recovery curve

A recovery curve, which expresses a chronological process in which an earthquake-damaged system is restored completely, is defined as a curve obtained by connecting the average values of a time-dependent system performance random variable plotted against time. To be more specific, a recovery curve can be calculated, by using the probability density function $f_R(r|t)$ of system performance r conditional on time t elapsed after the occurrence of earthquake damage, as follows:

$$R_D(t) = \int_0^{r_{\max}} r \cdot f_R(r \mid t) dr \tag{1}$$

where $R_D(t)$ expresses the recovery curve, and r_{max} is the maximum performance of the system. If it is assumed that all work for the restoration of system elements is carried out concurrently, the restoration time t may be considered independently for each element. This means that if the restoration time for an element is given, the probability density function $f_R(r|t)$ of system performance may be calculated discretely according to that time. The function is evaluated by the method described by Nojima (1999) and Nakamura *et al*. (2011) which dealt with system flow capacity. Eq. (1) can also be expressed by using the expectation of the random variable $R_{sys|t}$ conditional on the restoration time t. For the convenience of the subsequent formulation, the equation is rewritten as follows:

$$R_D(t) = E(R_{sys|t}) \tag{2}$$

2.2 Stock model

It is assumed that there is a certain amount of stock kept at an arbitrary location in a system as shown in Fig. 1. Hereafter in this study, that system is referred to as the stock model. In Fig. 1, a square represents a system element (e.g. manufacturing apparatuses), and a circle represents stock. Attention is turned to stock consumption. It is assumed that unfinished products or finished products are supplied from the stock if the performance of the upstream system falls below the performance of the downstream system. The random variable for stock consumption, $R_{con|t}$, can be calculated as the difference between the performance of the downstream system and that of the upstream system:

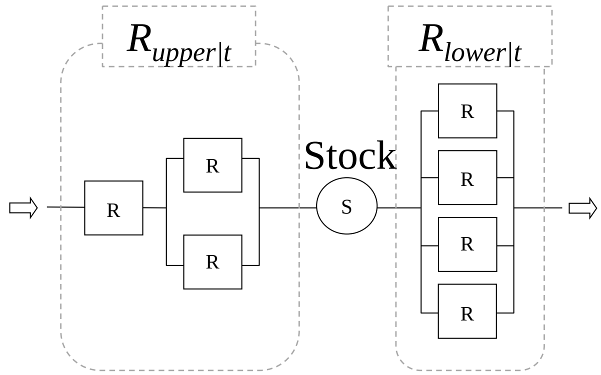


Fig. 1 – Example sketch of stock model

$$R_{con|t} = R_{lower|t} - R_{upper|t} \tag{3}$$

where $R_{lower|t}$ is a random variable for the performance of the downstream system conditional on the restoration time t, and, similarly, $R_{upper|t}$ is a random variable for the performance of the upstream system. When the variable $R_{con|t}$ is positive, supply comes from the stock. When it is negative, the amount of supply from the upstream system is greater than the capacity of the downstream system, and the amount of supply from the stock is zero. This condition needs to be imposed. Let z_m represent the maximum quantity that can be supplied from the stock per day. Since this is the upper limit of the quantity of supply per day, it is necessary to add this condition, too. Hence, the probability density function $f_{Rcon}(r|t)$ of the random variable $R_{con|t}$ for stock consumption can be expressed finally as

$$f_{R_{con}}(r\,|\,t) = \begin{cases} z_m & r > z_m \\ f_{R_{con}}(r\,|\,t) & 0 < r \le z_m \\ 0 & r \le 0 \end{cases} \tag{4}$$

The expectation of the stock left unused, z_a, can be obtained by subtracting total stock consumption from the total quantity of stock, z, as follows:

$$z_a = z - \int_0^{t_{\max}} E(R_{con|t})dt \tag{5}$$

where t_{max} is the maximum recovery time of the system. Since the stock function ends when the stock has been used up, zero (0) is obtained if z_a is a negative value.

A recovery curve that takes stock into consideration can be obtained by adding the expectation of the random variable of stock consumption, $R_{con|t}$, to the expectation of the random variable of system performance in the absence of stock, $R_{sys|t}$, as expressed below:

$$R_D(t) = E(R_{sys|t}) + E(R_{con|t}) \tag{6}$$

Eq. (6) shows the performance improving effect of stock. The recovery curve is improved as shown in Fig. 2.

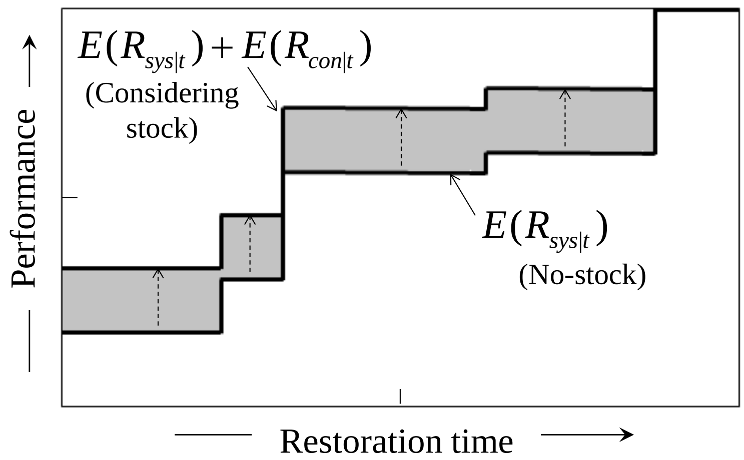


Fig. 2 – Improvement of the recovery curve by stock

3. Evaluation of Damage Correlation

3.1 Multiple integral of joint distribution function

Let us consider n correlated normal random variables Z_i, $i = 1, \ldots, n$ and calculate the intersection event probability $p(E_1, E_2, \ldots, E_n)$ such that $-\infty < Z_i \le h_i$ for all i. It is generally known that the probability in this case can be calculated by integrating the overlapping region of higher degree joint probability density functions $f(x_1, x_2, \ldots, x_n)$:

$$p(E_1 E_2 \cdots E_n) = \int_{-\infty}^{h1} \cdots \int_{-\infty}^{hn} f(x_1, \cdots, x_n) dx_1 \cdots dx_n \tag{7}$$

where $h_i = \Phi^{-1}\{p(E_i)\}$, where Φ is a cumulative distribution function of the standard normal distribution. Assuming that Z_i, $i = 1, \ldots, n$ is a normal random variable, it is expressed as a function of mutually independent standard normal random variables X_i, $i = 1, \ldots, n$ and Y:

$$Z_i = \sqrt{1-\theta_i^2} \cdot X_i - \theta_i Y \quad , i = 1 \sim n \tag{8}$$

where X_i and Y are independent, and θ is a parameter. By calculating Eq. (8) as a function of the random variables, the intersection event probability can be rewritten as a single integration formula (e.g. Curnow *et al*., 1962; Gupta, 1963):

$$p(E_1 E_2 \cdots E_n) = \int_{-\infty}^{\infty} \prod_{i=1}^{n} \left[\Phi\left(\frac{h_i + \theta_i y}{\sqrt{1-\theta_i^2}} \right) \right] \phi(y) dy \tag{9}$$

where φ is a probability density function of the standard normal distribution, and θ_i is related to the correlation coefficient ρ_{ij} of the random variable Z_i, i = 1, . . . , n as follows:

$$\rho_{ij} = \theta_i \theta_j \quad , i \neq j \tag{10}$$

where $0 < \theta_i \leq 1$.

3.2 Damage correlation coefficient of structures

Assume that there are n structures as shown in Fig. 3, and let C_i, i = 1, . . . , n represent the random variable for earthquake resistance and S_i, i = 1, . . . , n represent the random variable for intensity of the applied ground motion.

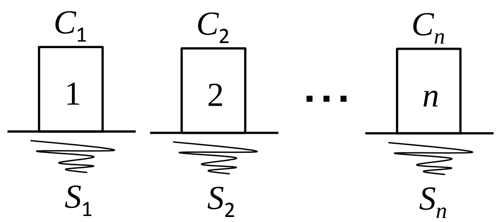


Fig. 3 – Definition sketch of earthquake resistance and seismic intensities

It is assumed that each random variable follows a logarithmic normal distribution, and each is defined as follows:

$$\begin{aligned} &f_{Ci}(\ln c \mid \lambda_{Ci}, \zeta_{Ci}) \quad , i = 1 \sim n \\ &f_{Si}(\ln r \mid \lambda_{Si}, \zeta_{Si}) \quad , i = 1 \sim n \end{aligned} \tag{11}$$

where λ and ζ are the logarithmic mean and the logarithmic standard deviation, respectively. The state of structural damage is defined as follows:

$$\frac{C_i}{S_i} = F_i \leq 1.0 \quad ; i = 1 \sim n \tag{12}$$

where it is assumed that the random variables C_i, i = 1, . . . , n are mutually independent and the random variables S_i, i = 1, . . . , n are perfectly correlated. By calculating the covariance between F_i and F_j, of the damage correlation coefficient between structures is calculated:

$$\rho_{ij} = \frac{\zeta_{Si} \zeta_{Sj}}{\zeta_{Fi} \zeta_{Fj}} \quad , i \neq j \tag{13}$$

where ζ_{Fi} , which is called a composite deviation, is related as follows:

$$\zeta_{Ci}^2 + \zeta_{Si}^2 = \zeta_{Fi}^2 \tag{14}$$

Assuming $\zeta_{Fi} = \zeta_F$, $i = 1, \ldots, n$, Eq. (13) is rewritten as follows:

$$\rho_{ij} = \frac{\zeta_{Si}\zeta_{Sj}}{\zeta_F^2} \quad ,i \neq j \tag{15}$$

From Eq. (10) and Eq. (15), the following relation is obtained:

$$\theta_i = \frac{\zeta_{Si}}{\zeta_F} \quad ,i = 1 \sim n \tag{16}$$

From Eq. (12), the following is derived:

$$\lambda_{Fi} = \lambda_{Ci} - \lambda_{Si} \quad ,i = 1 \sim n \tag{17}$$

3.3 Evaluation of intersection event probability considering damage correlation

In this section, the random variable F_i, $i = 1, \ldots, n$ is assumed to follow a multi-dimensional joint probability distribution (logarithmic normal distribution), and its application to Eq. (9) is considered. Since the range of integration is $0 < F_i \leq 1.0$, noting $\ln(1.0) = 0.0$, we obtain

$$h_i = \frac{-\lambda_{Fi}}{\zeta_F} \quad ,i = 1 \sim n \tag{18}$$

Applying Eq. (17) gives

$$h_i = \frac{-(\lambda_{Ci} - \lambda_{Si})}{\zeta_F} \quad ,i = 1 \sim n \tag{19}$$

Applying Eq. (16) and Eq. (19) to Eq. (9) gives

$$p(E_1 E_2 \cdots E_n) = \int_{-\infty}^{\infty} \prod_{i=1}^{n} \left[\Phi\left(\frac{\zeta_{Si} y + \lambda_{Si} - \lambda_{Ci}}{\zeta_{Ci}} \right) \right] \phi(y) dy \tag{20}$$

Thus, a formula for intersection event probability calculation taking account of correlation has been derived. The various combination event probabilities can also be evaluated in a similar way. Since the standard normal cumulative probability function of Eq. (20) directly incorporates physical quantities such as earthquake resistance and intensity of the applied ground motion, the equation is easy to understand and convenient to use.

Assume that the same damage correlation coefficient is applicable to *n* structures. This is represented by ρ_F, and ρ_F and the composite deviation ζ_F are taken as given conditions. Then, Eq. (15) can be rewritten as

$$\zeta_S^2 = \rho_F \zeta_F^2 \tag{21}$$

Hence, ζ_S can be calculated, and, by using Eq. (15), ζ_C can also be calculated:

$$\zeta_C^2 = \zeta_F^2 - \zeta_S^2 \tag{22}$$

By applying ζ_S, ζ_C, λ_S and λ_C to Eq. (20), the various combination event probabilities under the condition of the damage correlation ρ_F can be calculated.

4. Modeling of Example Case of Calculation

As an example, this section looks at a production process involving a number of manufacturing apparatuses. Fig. 4 shows a system model of the production process. Each square represents a manufacturing apparatus, and the production system consists of three processes (stages): A&B , C and D. The production equipment for each process consists of a number of apparatuses having the same functions placed in parallel. Table 1 shows the specifications of the manufacturing apparatuses. For example, the C process has four apparatuses (R_C) each capable of processing 150 products per day so that up to 600 (150 × 4) products per day can be processed. Similarly, the A&B process is capable of processing up to 600 products per day, and the D process up to 500 products per day. By referring to Nakamura *et al*. (2011), the state of earthquake-induced damage to the manufacturing apparatuses was classified either as minor or major, and the mean values of the corresponding earthquake resistance values were translated to acceleration values. These correspond to the mean values λ_{Ci} of earthquake resistance in Eq. (20). The restoration periods for apparatuses that have suffered minor and major damage were assumed to be 3 days and 30 days, respectively. For the purpose of discretization, therefore, t = 3 days and t = 30 days were assumed, and the maximum restoration period of the system was assumed to be t_{max} = 30 days on the assumption that restoration work is carried out concurrently.

The mean value of the intensity (acceleration) of the applied ground motion was assumed to be 400 Gal for all apparatuses. The composite deviation ζ_F that takes account of the variability of seismic intensity and earthquake resistance was assumed to be 0.5.

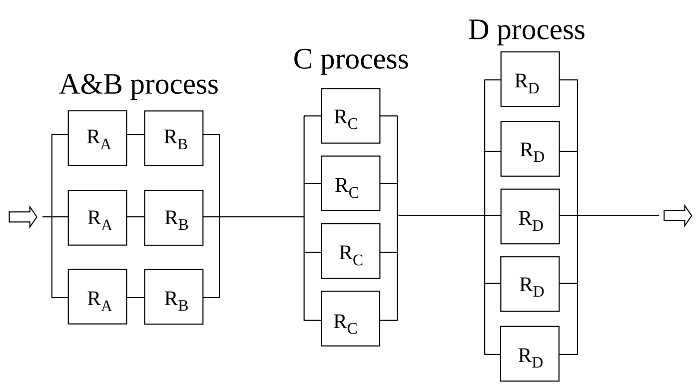


Fig. 4 – System model consisting manufacturing apparatuses

Table 1 – Specifications of the manufacturing apparatus (Nakamura *et al*. 2011)

Compornent	Performance (per day)	Damage mode	Earthquake resistance (median of strength) (Gal)	Restration time (day)
R_A	200	Minor	700	3
		Serious	800	30
R_B	200	Minor	440	3
		Serious	600	30
R_C	150	Minor	400	3
		Serious	500	30
R_D	100	Minor	420	3
		Serious	550	30

According to Nojima (1999) and Nakamura *et al*. (2011), which dealt with maximum flow problems, the random variable for the performance of the system model, $R_{sys|t}$, can be calculated as in Eq. (23):

$$R_{sys|t} = \min\left\{\sum_{i=1}^{3}\min\left(R_{A|t}, R_{B|t}\right)_i, \sum_{i=1}^{4} R_{Ci|t}, \sum_{i=1}^{5} R_{Di|t}\right\} \tag{23}$$

where $R_{A|t}$ to $R_{D|t}$ are the random variables for the performance of each apparatuses dependent on restoration time t.

Fig. 5 shows the system model of Fig. 4 that takes stock into consideration. A circle represents stock; S_B and S_C represent unfinished products, and S_D represents products.

The random variable for stock consumption, $R_{con|t}$, conditional on the restoration time t can be expressed as in Eq. (24) if stock is available at S_B and as in Eq. (25) if stock is available at S_C. If stock is available at S_D, the random variable on the upstream side becomes the same as in Eq. (23). Note that the condition of Eq. (4) is imposed in each case. The recovery curve that takes stock into consideration can be calculated, as shown in Eq. (6), by adding the expectation of $R_{con|t}$ to the expectation of $R_{sys|t}$.

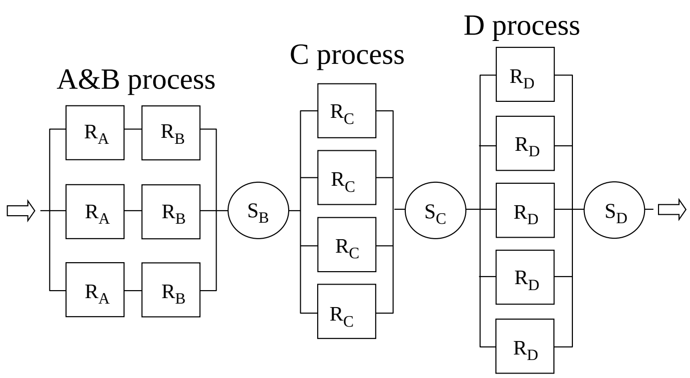


Fig. 5 – System model consisting manufacturing apparatuses with stock

$$R_{con|t} = \min\left(\sum_{i=1}^{4} R_{Ci|t}, \sum_{i=1}^{5} R_{Di|t}\right) - \sum_{i=1}^{3} \min\left(R_{A|t}, R_{B|t}\right)_i \tag{24}$$

$$R_{con|t} = \sum_{i=1}^{5} R_{Di|t} - \min\left\{\sum_{i=1}^{3}\min\left(R_{A|t}, R_{B|t}\right)_i, \sum_{i=1}^{4} R_{Ci|t}\right\} \tag{25}$$

5. Calculation Results and Discussion

To calculate the four cases shown in Table 2. The total quantity of each stock is z = 1000, and the maximum quantity of supply per day is z_m = 500. It is assumed that stock consumption does not occur concurrently; instead, it occurs individually. The damage correlation coefficient ρ_F is varied between 0.0 (independent), 0.5, 0.8 and 1.0 (perfectly correlated), and their recovery curves are determined. As shown in Table 2, Case 0 is a no-stock case, and Case 1, Case 2 and Case 3 are the cases in which stock is available at S_B, S_C and S_D, respectively.

Table 2 – Calculation cases

Case No.	Location of stock	Kind of stock	Amount of Stock (z)	Amount of maximum stock supply (z_m) (per day)
0	—	—	—	—
1	S_B	Unfinished product	1000	500
2	S_C			
3	S_D	Finished product		

Fig. 6 shows the calculation results (recovery curves) in each case. Fig. 6 (a), (b), (c) and (d) show the no-stock (Case 0), stock S_B (Case 1), stock S_C (Case 2) and stock S_D (Case 3) cases, respectively. The legend box in each graph shows the damage correlation coefficient, ρ_F, and the amount of stock left unused, z_a, where z_a = 0 means that the stock has been used up and z_a = 1000 means that the stock remains unused.

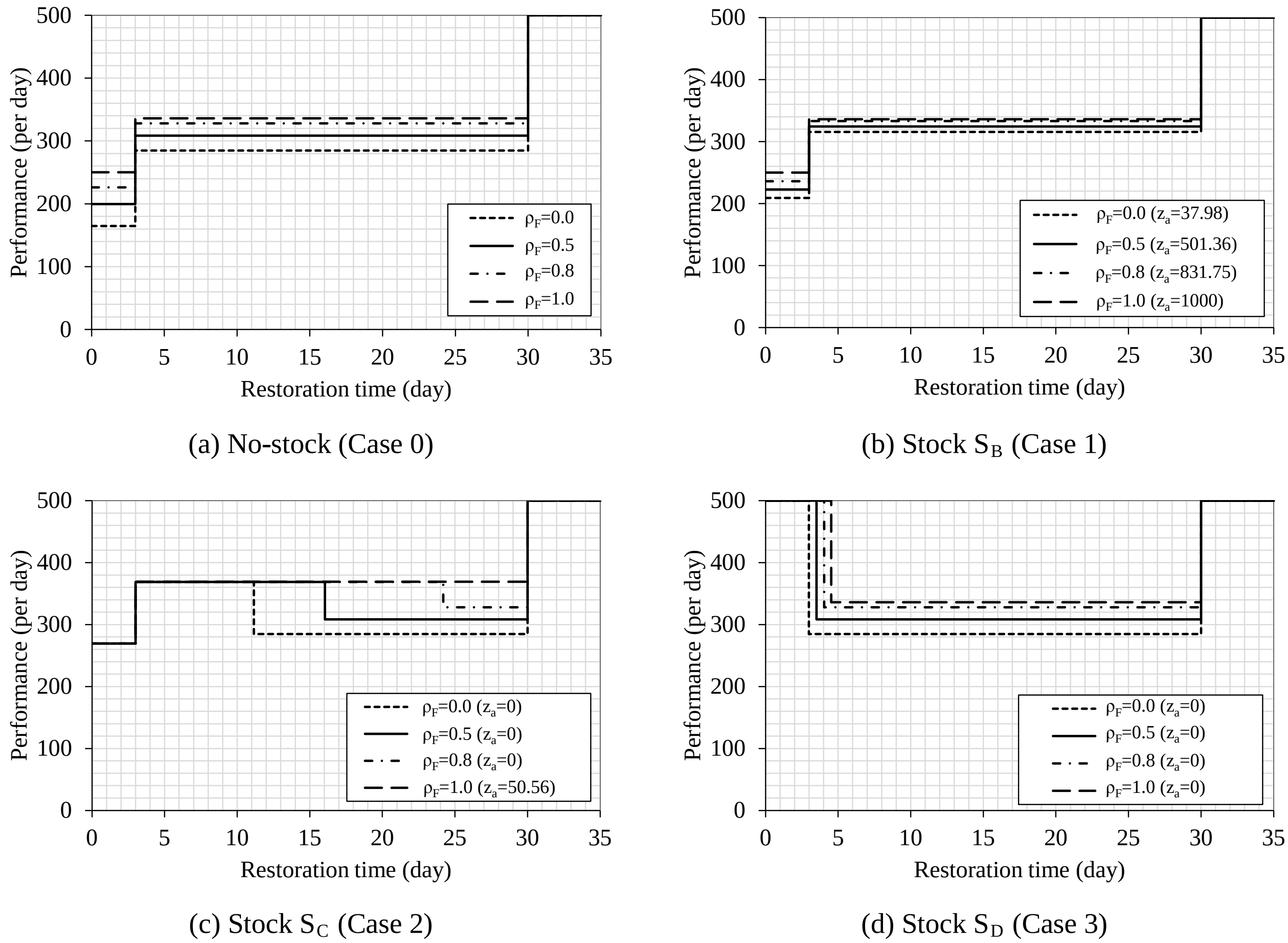
In Case 0 of Fig. 6 (a), the recovery curves show some differences in daily production performance because of the differences in the damage correlation. As can be seen from the recovery curves, as the degree of correlation decreases (as the degree of independence increases), the degree of decrease in production performance increases. This is due mainly to the minimum performance calculation for the serial connection sections of the manufacturing system. Doi *et al*. (2013) has reported similar findings.

The recovery curves in Case 1 of Fig. 6 (b) resemble the curves in Case 0 in shape. The recovery curve for perfect correlation is identical to the perfect correlation recovery curve in Case 0. This is partly because the earthquake resistance of the A&B process located upstream is higher than that of the C and D processes located downstream and partly because perfect correlation has made the occurrence of damage on the upstream side alone an empty event. As a result, stock consumption did not occur and the result became practically the same as in no-stock case (Case 0).

As can be seen from the recovery curves in Case 2 of Fig. 6 (c), as the degree of the damage correlation decreases, the stock is used up faster. In the perfect correlation case, a small percentage of the stock was still left unused (stock left unused z_a = 50.56) even after the 30-day restoration period ended. This indicates that the quantity in stock is too large under the perfect correlation scenario.

The Case 3 recovery curves of Fig. 6 (d) show that the system goes into operation immediately after the occurrence of the earthquake and remains operating at maximum performance of the system 500/day, regardless of the degree of the damage correlation. The stock, however, is used up in less than five days (see the information in the stock left unused, z_a, in the legend box), and the system returns to the no-stock production performance (Case 0).

As shown in Fig. 6, if locating stock in the second half of system, It tends to be high stock consumption. hence, system performance improvement by effect of stock become remarkably. As the degree of the damage correlation increases, stock consumption tends to decrease.



(a) No-stock (Case 0)

(b) Stock S_B (Case 1)

(c) Stock S_C (Case 2)

(d) Stock S_D (Case 3)

Fig. 6 – Comparison of the recovery curve considering the damage correlation

In the example shown in Fig. 6, the rate of supply (z_m) from the stock is assumed to be 500/day, which is the same as the normal production maximum performance of 500/day. Consequently, among various combination events of possible damage suffered by the upstream and downstream processes, if, for example, upstream damage is 100 and downstream damage is 300, then 200 (200 = 300 − 100) is supplied from the stock. In that case, the apparent state of the upstream side becomes normal. Thus, if the rate of supply from the stock per day is equal to or greater than the production performance of the system model, recovery curves are determined solely by the state of damage on the downstream side, regardless of the degree of damage on the upstream side. In view of this, let us again compare the recovery curves for the three days following the occurrence of the earthquake in Case 1 of Fig. 6 (b) and Case 2 of Fig. 6 (c). Fig. 6 (b) shows four patterns of performance degradation due to the damage correlation, while Fig. 6 (c) shows uniform performance degradation, regardless of the degree of the damage correlation. The reason for this is as follows. The Case 1 recovery curves in Fig. 6 (b) are determined by the first term of Eq. (24), and four patterns of performance degradation appeared because of the minimum calculation included in the equation. The Case 2 recovery curves in Fig. 6 (c) are determined by the first term of Eq. (25), but the equation involves adding up random variables, and the expectation thus calculated is not affected by correlation. This is why uniform performance degradation was shown, irrespective of the damage correlation.

Nakamura *et al*. (2011) defined the expectation of system restoration time (hereinafter referred to as "restoration time expectancy," or "RTE") as follows:

$$RTE = \int_0^{t\max} \left(r_{\max} - R_D(t) \right) / r_{\max} dt \tag{26}$$

where t_{max} is the maximum restoration time and r_{max} is the daily production maximum performance. What Eq. (26) does is equivalent to measuring the daily production maximum performance (in this example, r_{max} = 500) on the vertical axis of the recovery curve graph and calculating the area of the region above the recovery curve. The function $R_D(t)$ in Eq. (26) draws the recovery curve taking stock into consideration shown in Eq. (6). It is shown comprehensively that the smaller the RTE value, the greater the performance improvement becomes.

Fig. 7 compares the RTE values resulting from different degrees of the damage correlation. As shown, taking stock consumption into consideration reveals that RTE tends to become smaller, indicating the effectiveness of stock. As the degree of the damage correlation increases further, RTE tends to become shorter. This is because when the degree of the damage correlation is high, low-damage-probability events are included in high-damage-probability events. The perfect correlation curves in Case 0 and Case 1 show the same RTE value. This is because the stock was not used in Case 1 (stock left unused z_a = 1000) as shown in the legend of Fig. 6 (b). The non-perfect-correlation curves in Case 2 and Case 3 show the same RTE values although the recovery curves differ in shape. The reason for this is that in both cases the stock is mostly used up within 30 days (maximum restoration period t_{max}) (see the stock left unused, z_a, shown in the legend boxes of Fig. 6 (c) and (d)).

The recovery curve improving effect of stock consumption depends on the total amount of stock and the maximum quantity of supply per day. If, therefore, the stock is left unused, it means that the total amount of stock is excessively large. Conversely, if the stock is used up early, it means either that the total amount of stock is too small or that the daily supply rate is too high. In the proposed method, these factors can be evaluated quantitatively. This indicates that by setting in advance the quantity of products to be supplied to the market in the event of earthquake damage, it is possible to determine the optimum amount of stock needed to maintain that quantity and the quantity to be supplied per day.

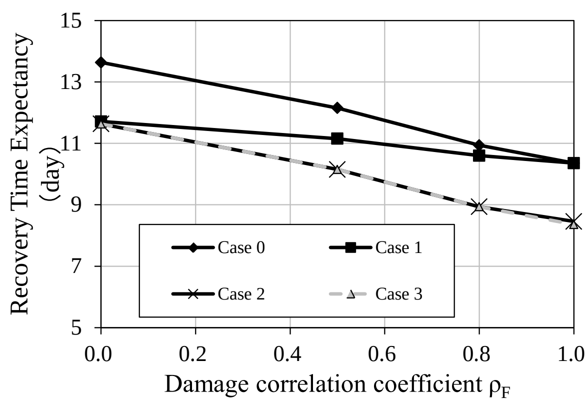


Fig. 7 – Comparison of the Recovery Time Expectancy

6.Conclusion

A method of evaluating post-earthquake recovery curves taking account of the damage correlation applicable to production processes and a method of evaluating the recovery curve improving effect of stock have been proposed. The proposed method was applied to a production line consisting of a number of manufacturing apparatuses to evaluate the influence of the damage correlation on the effectiveness of stock. The results obtained in this study are as follows:

· The recovery curve considering stock is not a monotonous increase, because It returns to the recovery curve of the no-stock case when stock is exhausted.

· The recovery of production performance can be improved, compared with the no-stock case, by taking stock consumption into consideration. Especially, if locating stock in the second half of system, It tends to be high stock consumption. hence, system performance improvement by effect of stock become remarkably.

· If stock consumption is not taken into consideration, production performance improves as the degree of the damage correlation increases. Consequently, RTE becomes shorter.

· If stock consumption is taken into consideration, stock consumption decreases as the degree of the damage correlation increases. As a result, stock availability time becomes longer.

· If stock is used up before the end of the maximum restoration period (in the example shown, 30 days), RTE is the same.

· It is necessary to take the damage correlation into consideration because stock consumption is strongly affected by the damage correlation between apparatuses.

The results obtained in this study do not necessarily show a general tendency because they are dependent upon the system model used, the total amount of stock and the maximum quantity of supply per day. Nevertheless, it has been shown that if the quantity of products to be supplied to the market in the event of earthquake damage is set in advance, the proposed method makes it possible to determine the optimum amount of stock needed to maintain that quantity and the daily supply capacity. The development of a method of stock quantity optimization is a subject for further study.

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