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# A CRITICAL LITERATURE REVIEW OF MULTIFACTORIAL CONSIDERATIONS IN INCREMENTAL DYNAMIC ANALYSIS (IDA), THE COMBINED APPLICATION OF IDA AND ARCGIS, AND ANN-BASED IDA METHODOLOYIES

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**Abstract:**

The Incremental Dynamic Analysis (IDA) method has been widely applied in structural design and assessment due to its ability to accurately predict structural failure or collapse probabilities. Extensive research has explored its application in optimizing structural design schemes. However, conventional IDA approaches often overlook several critical factors, such as the diversity of earthquake intensity measures, the existence of multiple failure modes, and regional variations in seismic risk—particularly in the context of seismically isolated structures. Moreover, the integration of IDA with Geographic Information Systems (GIS) and the use of Artificial Neural Networks (ANNs) to improve computational efficiency remain underexplored. This article reviews recent studies on the application of IDA that consider multiple influencing factors, the integration of GIS with IDA, and ANN-based enhancements of IDA methodologies. Additionally, it identifies key research gaps in the application of IDA to seismically isolated structures, offering guidance for future investigations.

**Keywords:**

ArcGIS, Artificial Neural Network, Computation Time, Incremental Dynamic Analysis, Multiple Failure Modes.

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## Introduction

The resistance of a structure or building to the earthquake is crucial to human beings, those were studied by many researchers during a long period (Sooria et al., 2012; Ismail et al., 2014; Ismail et al., 2017a; Ismail et al., 2017b; Ismail et al., 2018a., Ismail et al., 2018b., Ismail et al., 2021; Ismail et al., 2022; Rozaina et al., 2023). Seismic isolation is one of the most efficient structure designs to resist earthquake energy. Many methods can be used to evaluate its safety factors, including the Incremental dynamic analysis (IDA). IDA is a performance-based method that quantifies the probability of structural failure under specific earthquake intensity measures. It has been widely utilized in numerous studies to evaluate the collapse risk of seismic isolated structures. This article firstly explores research on IDA that utilizes in many engineering projects. Then IDA method considering various combinations of earthquake intensity measures (IMs) were demonstrated, including some novel combinations and the advantages they offer. After that, it presents how a newly presented IDA method by Liu et al. (2023) considers multiple failure modes and earthquake probabilities in specific regions. After that, this article provides reviews on the application of GIS system in IDA process and the ANN based IDA method used in bridges and tunnels. Finally, these reviews were discussed, and some future research areas were proposed based on the research gaps determined in this review study. The detailed outline of this review is presented as follows (Figure 1):

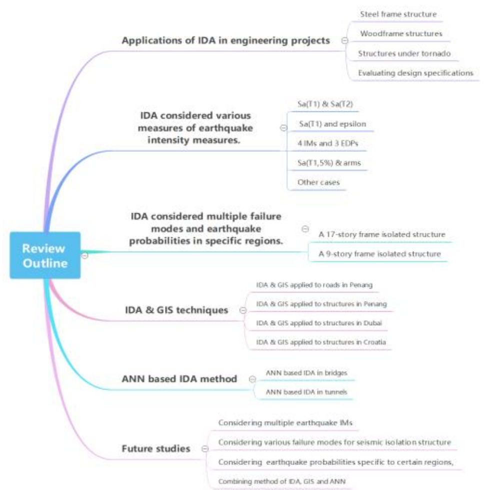


**Figure 1: Review Outline**

## Applications Of IDA In Engineering Projects

Incremental dynamic analysis can be used in many engineering fields to accurately determine the damage and collapse probabilities of structures. These fields include, but are not limited to, steel structure, wood frame structure, reinforce concrete structures, etc. IDA is often used to evaluate the performance of these structures under wind or seismic forces, and it can also conduct systematic evaluations of existing structural design specifications. Below are the findings of IDA's application in various aspects.

### *IDA Used In Steel Frame Structure Incorporating The Elements Database*

The collapse probability can be predicted more accurately by considering the degradation of structure elements. Usually, this elements degradation problem is attributed to repeated loading process. In the first part of this study, Lignos and Krawinkler (2012) constructs a database of structural strength degradation and emphasizes the application of this database to specific projects. These components include W-section steel beams, tubular hollow square steel

Journal of Information System and Technology Management
JISTM
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DOI: 10.35631/JISTM.1039009
columns and reinforced concrete beams, a total of 600 experimental objects. Their size, material properties and other characteristics were recorded, and experiments were carried out on them to obtain their degradation properties. The degradation properties of these structural members include the key indexes like residual strength and ultimate deformation. In the second part of this study, they first analyzed a 4-story steel frame structure for shaking table experiments. Through this shaking table experiment, the indexes such as story drift ratio and base shear force at structure collapse were obtained. By comparing the results of the numerical simulation experiment and the results of the shaking table experiment, it is found that the numerical simulation experiment considering the structural degradation attribute can more accurately predict the actual performance of the structure on the shaking table. Before IDA analysis, they input the information of components from the established database into the software, including load-displacement hysteretic diagram, moment-rotation hysteretic diagram, material properties, geometries and so on, so that the nonlinear properties of the structure can be reflected more accurately. Furthermore, the study employed 40 seismic waves to evaluate its collapse fragility curves.

***IDA Used In Wood frame Structures***

The assessment and optimization of seismic performance of wood structure building is also one of the application areas of IDA method. Ioannis et al. (2023) used Seismic Analysis of Woodframe Structures (SAWS) to model two wooden structures, a two-storey townhouse and a three-storey apartment building. IDA is used to analyze two wood structures. In this analysis, median spectral acceleration (Sa) at 0.2 seconds was used as the Intensity measure (IM). Maximum story drift is used as the basis for judging the collapse of the structure. When the maximum story drift of the structure exceeds 0.07 (7%), the structure is defined as collapsed. Ioannis et al. (2023) calculated the fragility curves of these structures: (1) The collapse probability of Woodframe buildings is related to the construction quality. When the construction quality is improved from poor to average, The median collapse intensity increased by 15%. This means that the better the construction quality of the structure, the lower the collapse probability. It is worth mentioning that the setting of construction quality is achieved by adjusting the indices of structural stiffness and strength in the software; (2) The bi-directional excitations reduce the median collapse level of the house by 20% compared to uni-directional excitations. This indicates that the effect of bidirectional earthquakes makes the seismic force dispersed on the seismic members of the structure in two directions, which makes the collapse probability of the structure lower; (3) The collapse rate of the re-designed houses is lower than that of the original ones. This is because more wood shear wall is added to the redesigned house, which improves the earthquake resistance; (4) Structural wall decoration, such as the use of drywall and cement, can reduce the risk of collapse. This is because the wall decoration increases the strength and stiffness of the structure, and makes the structure more able to dissipate earthquake energy.

***IDA Used In Predicting The Fragility Function Of Structures Under Tornado***

IDA can also be used to predict the probability of structural collapse due to wind. David et al. (2017) studied the tornado that occurred in Joplin, Missouri on May 22, 2011, and used this as a basis to evaluate the damage effect and probability of the Tornado on the structure. This study adopted the IDA method, in which the intensity measures of wind were mainly evaluated in three ways: a. tree-fall model, this model analyzes the pointing, damage width and damage ratio of trees after collapse. b. Rankine vortex model. This model is used to describe the velocity distribution of the Tornado wind field. c. Comparison of Mean Squared Error (MSE).

Journal of Information System and Technology Management
JISTM
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This refers to the MSE between the maximum wind speed of the tree-fall model at the comparison point and the wind speed through the Enhanced Fujita scale (EF). The accuracy of the wind field model is enhanced by minimizing the MSE. The degrees of damage (DOD) adopted in this IDA method is the basis for judging the collapse of a structure. When DOD is greater than or equal to 4, the structure is judged to be collapsed. Through analysis, David et al. (2017) concluded that the tornadoes in open areas are more destructive to the structure than those in suburban areas, with the tornado load factor (TLF) ranging from 1.37 to 1.55.

***IDA Used In Evaluating Two Structure Design Specifications***

IDA analysis can be used as a foundational tool for evaluating the quality of design specifications. Typically, an IDA analysis by Haselton et al. (2011) was conducted on thirty models of reinforced concrete buildings to compare and assess the applicability and rationality of two design codes: ASCE 7-02 and ASCE 7-05. Thirty-nine far-field ground motions were used for this IDA analysis. Furthermore, the Intensity measure chosen for this IDA analysis is spectral acceleration at the first-mode period (Sa(T1)). The Demand measures selected for this IDA analysis are maximum story drift. Unlike conventional IDA analysis, in which the structure collapse is determined based on whether the maximum story drift exceeding the limit, this approach analyzes each function independently. Structure will be defined as collapsed when the story drift remains constant as Sa increases. By comparing the ACE 7-02 and ASCE7-05 codes, Haselton et al. (2011) found that the collapse risk of high-rise buildings designed in accordance with ASCE7-05 was significantly increased due to the reduction of the minimum base shear force.

**IDA Considered Various Earthquake Intensity Measures (IMs)**

Although various failure modes of buildings have been considered in some studies, normally only a single intensity measure (IM) is typically used, with PGA being the most commonly employed. However, when conducting vulnerability analysis on structures, a single IM may be insufficient to effectively represent ground motion and may result in significant dispersion of results (Li et al., 2014). The following studies focuses on selecting various intensity measures to improve the efficiency and accuracy of incremental dynamic analysis method utilized in predicting the fragility curves of structures.

***IDA Taking First And Second Spectral Acceleration Sa(T1) & Sa(T2) As Dual Intensity Measures (IMs)***

The IDA method considering multiple ground motion Intensity measures (IMs) is studied in this paper by Li et al. (2014). Compared with the general method only considering a single IM, this method can reflect the information of ground motion more accurately, so as to predict the collapse probability of the structure more accurately. In this study, they selected the first spectral acceleration Sa (T1) and the second spectral acceleration Sa (T2), which represent the spectral values of the acceleration response corresponding to the structure in the first and second periods, respectively. They apply this IDA method, which considers two IMs, to analyze a bridge with a span of 88m and a height of 12m. After considering the three uncertainties of 1.the yield strength of the steel bar, 2. the compressive strength of the concrete and 3.the bulk density of the superstructure, ten random structural models were obtained according to the Latin hypercube sampling method. While using the OpenSees to establish and analyze these models, 10 seismic waves were selected for each bridge structure, resulting in 100 groups of sample pairs of structure & ground motion. In addition, this study analyzed a total of three main structural components that make up the bridge: piers, abutments and

Journal of Information System and Technology Management JISTM
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DOI: 10.35631/JISTM.1039009
supports. Each component considers two IMs, namely Sa(T1) and Sa(T2), and their corresponding demand measures. Furthermore, the influence of near-field earthquakes and general site earthquakes on bridge failure probability is compared and analyzed. Finally, the following conclusions are drawn: (1) IDA analysis of a reinforced concrete bridge using Sa(T1) and Sa(T2) as Intensity measures(IMs) of ground motion can improve the accuracy of structural damage level prediction and reduce the dispersion of its prediction results; (2) The fragility surface formed by considering the two IMs can effectively reflect the change of the failure probability of the components of the bridge; (3) For this bridge, the failure probability under near-field earthquake is significantly higher than that under general ground motion.

***IDA Taking Spectral Acceleration At Period T1 (Sa(T1)) And Epsilon As Intensity Measures (IMs)***

Furthermore, Baker and Cornell (2021) presented a new approach to IDA that uses two indicators as Intensity measures (IM) instead of one in the traditional method. These two indices are: spectral acceleration at period T1 (Sa(T1)) and epsilon. Epsilon is calculated by subtracting the predicted mean ln (Sa(T1)) from the recorded ln (Sa(T1)) and dividing by the log standard deviation. Using Epsilon as the second IM complements the insufficiency of the IM prediction using a single IM Sa(T1). Sa(T1) only considers the response of the structure in the first mode period, while Epsilon also considers the variability of spectral accelerations across different ground motions, recognizing that multiple ground motions may yield the same Sa(T1) but differ in other periods. The structural demand measures are maximum story drift. Then they employed this new IDA method to analyze a frame structure built in the 1960s, as well as 15 other frame structures. In the course of this analysis, 40 sets of seismic waves were used for each of the two types of structures. Finally, they found that the epsilon value of the earthquake has a greater impact on the structure collapse probability than the earthquake magnitude and epicenter distance.

***IDA Considering Four Intensity Measures (IMs) And Three Engineering Demand Parameters (EDPs) With Their Combinations***

Additionally, in Modica & Stafford's study (2013), the IMs used in their IDA process included: spectral shape parameter (Np), Arias Intensity (AI), Spectral acceleration at the initial fundamental period (Sa(T1)) and the significant duration of the Arias intensity (D575). Modica & Stafford (2013) also considered a variety of Engineering demand parameters (EDP), including Maximum Inter-story Drift Ratio (MIDR), Normalized Hysteretic Energy (NEH) and Inter-Story Drift Peak Acceleration (IDPA). Modica & Stafford (2013) then subdivide this IDA method into: the method considering the combination of a single IM and a single EDP, resulting in a total of 12 combinations. The method combining multiple IM with a single EDP, resulting in a total of 24 combinations. After that, Modica & Stafford (2013) used these IDA analysis methods to calculate five European frame structures, and draw the following conclusions (Modica & Stafford, 2013): (1) Considering the vector combination of three IMs is not efficient to improve the calculation accuracy, and it is not much different from the standard deviation of the result calculated by considering only two IMs; (2) Considering the vector combination of two IMs is more accurate than considering only a single IM; (3) Among the many combinations, the one with the lowest standard deviation obtained is the one with Ln (Sa)+Ln (Np) as IMs and Ln (MIDR) as EDP. In this scenario, the standard deviation is reduced by about 30%-40% compared to considering only a single IM (Modica & Stafford, 2013).

Journal of Information System and Technology Management
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### *IDA Considering The Ground Motion Intensity And Duration*

Different combinations of IMs are typically employed for distinct purposes and objects. In addition to the aforementioned combination, Cheng et al. (2021) takes into account the dual influence of ground motion intensity and time duration, namely two IMs: Sa (T1,5%) as the ground motion intensity index and root-mean-square acceleration a(rms) as the ground motion index considering time. The maximum story drift θmax serves as the parameter for assessing model failure (Cheng et al., 2021). Subsequently, three sets of frames consisting of 5, 8, and 10 layers respectively are subjected to analysis, to investigate the impact of earthquake duration, two sets of 140 ground motion records were selected, one with a prolonged duration (exceeding 25 seconds) and the other with a short duration (less than 25 seconds). Then, the BP neural network method was employed to process the data of the a(rms), thereby reducing its dispersion, and enhancing the reliability of results. Subsequently, fragility surfaces for those structures were obtained, with Figure 2 and Figure 3 depicting the fragility surface of the five-story frame structure.

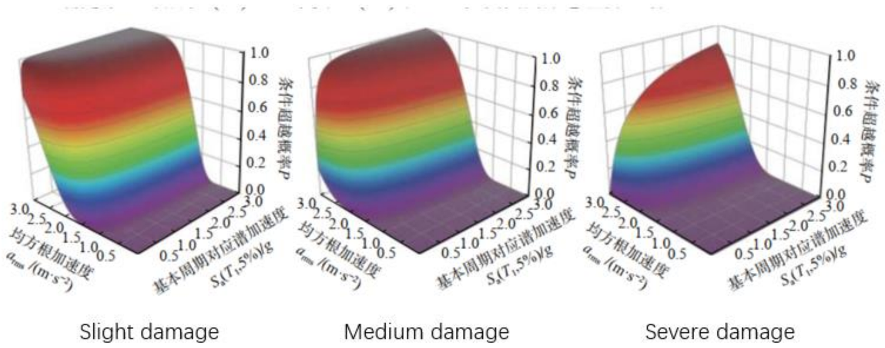


**Figure 2: Fragility Surfaces Under Long-Duration Earthquake**

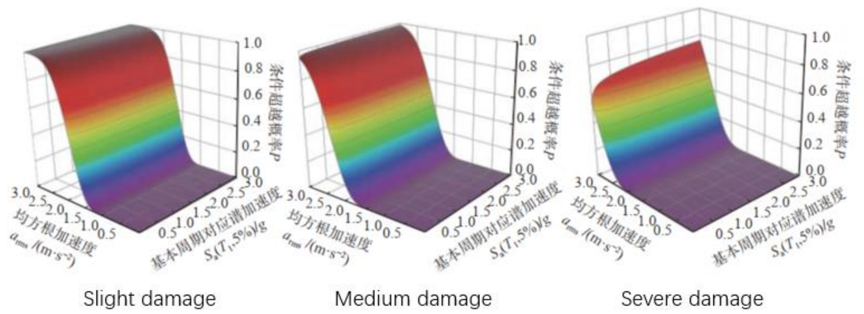


**Figure 3: Fragility Surfaces Under Short-Duration Earthquake**

Cheng et al. (2021) found that the BP neural network method can comprehensively consider ground motion intensity and time duration, reducing data dispersion and enhancing result reliability. Furthermore, the impact of duration on structures is dependent upon the level of ground motion intensity, only when local earthquake intensity reaches a certain threshold will earthquake duration have an effect on structures.

### *Other Cases And Limitation*

The spectral displacement 1 SD (T1, period of first mode) and spectral displacement 2 SD (T2, period of second mode) were utilized by Seyedi et al. (2009) as IMs for conducting IDA analysis on a building and deriving its fragility surface. Furthermore, Tothong and Cornell (2022) compares the traditional IM with newly proposed IMs, highlighting that the traditional

Journal of Information System and Technology Management
JISTM
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Volume 10 Issue 39 (June 2025) PP. 135-151
DOI: 10.35631/JISTM.1039009

IMs based on elasticity, for example, pseudo-spectral acceleration or vector of Sa and epsilon, show a large deviation when evaluating near-source pulse-like ground motions. Therefore, they used advanced ground motion intensity measures, including IM(1I&2E) and the inelastic spectral displacement, S(di) to conduct IDA analysis. Through comparison, it has been determined that the advanced IMs can better capture the earthquake effect of pulse-like ground motion, thereby increasing the accuracy of IDA results.

The utilization of two IMs can mitigate the dispersion of data (Baker and Cornell, 2021； Tothong & Cornell, 2022；Seyedi et al., 2009；Modica & Stafford, 2013；Li et al., 2014； Cheng et al., 2021), leading to more precise outcomes. However, the degree of data improvement varies when different combinations of IMs are used, and different research objects should also be considered, especially for SI structures. This is one of the study gaps that requires further investigation.

**IDA Considered Multiple Failure Modes And Earthquake Probabilities In Specific Regions For Seismic Isolation Structure**

Specifically for seismic isolation structure, after considering two types of parameters as IMs, fragility surfaces were obtained instead of fragility curves. Taking into account multiple failure modes of seismic isolated structures, then different fragility surfaces can be derived. However, such results have not yet incorporated earthquake probabilities in specific regions. Next, this report will provide a detailed analysis of an article published by Liu et al. (2023) that focuses on the Incremental Dynamic Analysis (IDA) of seismic isolation systems. In their study, the earthquake probability of various different geographical locations and different failure modes of certain seismic isolation structures are considered.

***IDA Considering Four Failure Modes & Earthquake Probability In Specific Regions In A 17-Story Frame Isolated Structure***

Liu et al. (2023) has conducted similar research. Although the consideration of two parameters as IMs to obtain fragility surfaces was not included in their study, multiple failure modes and earthquake probabilities in specific regions were simultaneously taken into account. Liu et al. (2023) first built a model for a 17-story idealized framework structure (as shown in Figure 4) and analyzed the story drift of the superstructure, then the horizontal displacement, the compressive stress and tensile stress limits of the isolators were analyzed, which correspond to failure modes 1, 2, 3 and 4 respectively. Three representative isolators from the side, the middle and the corner are selected for comparison (Figure 5 and Figure 6).

Liu et al. (2023) discovered that the probability of failure in horizontal displacement is essentially equivalent across all three forms of isolators. The compressive stress values of the isolators are generally higher on the side or corner than in the middle, with their maximum values used. Furthermore, there is not much difference in tensile stress for isolators on the side or corner, and their maximum value is used. Multiple fragility curves are then derived for different failure modes with increasing acceleration. By combining these with earthquake probability, a damage probability curve is obtained, as shown in Figure 7. Based on this analysis, recommendations for structural design can be made. That means in this 17-story idealized framework structure, they not only consider multiple failure modes, but also integrates earthquake probability and fragility curves to derive damage curves. Finally, design recommendations are proposed based on the damage probability of four failure modes.

Journal of Information System and Technology Management
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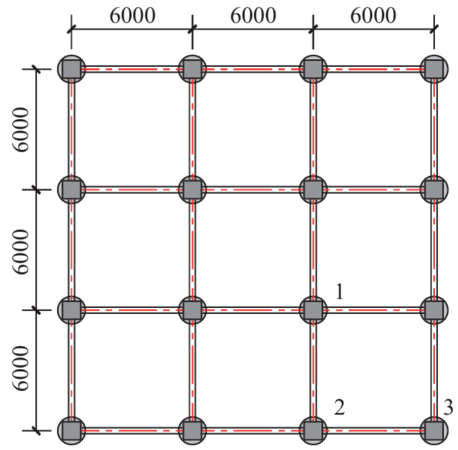


**Figure 4: Structural Plan For A 17-Story Idealized Framework Structure**

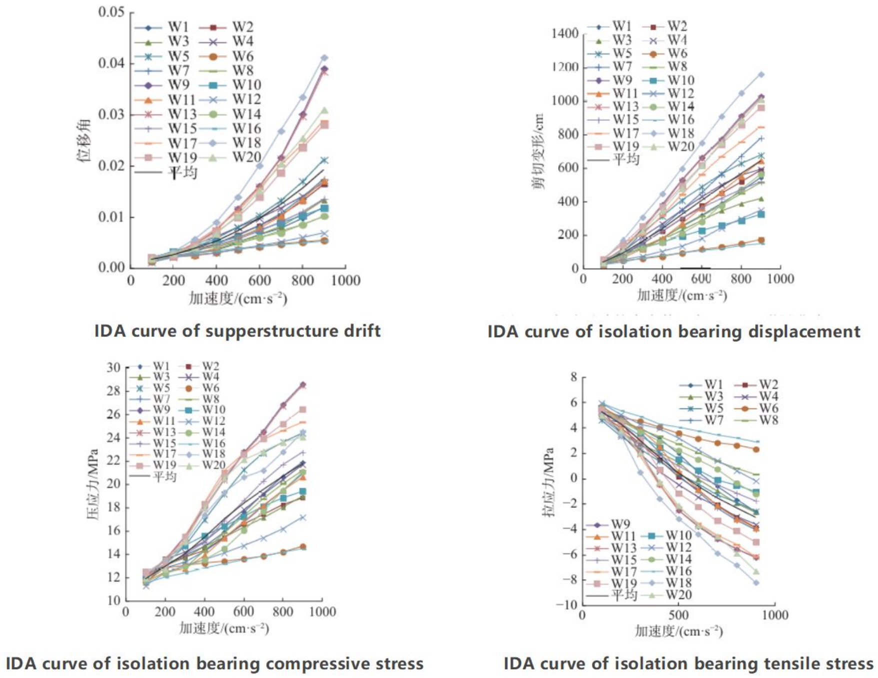


**Figure 5: IDA Curves Of Isolators Under Different Failure Modes In The 17-Story Structure**

Journal of Information System and Technology Management
JISTM
EISSN: 0128-1666
Volume 10 Issue 39 (June 2025) PP. 135-151
DOI: 10.35631/JISTM.1039009

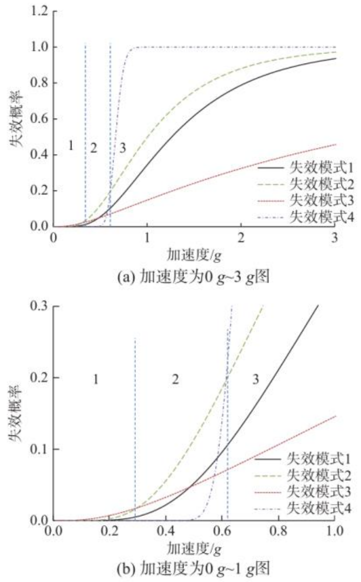


**Figure 6: Fragility Curves Of Four Failure Modes(1st)**

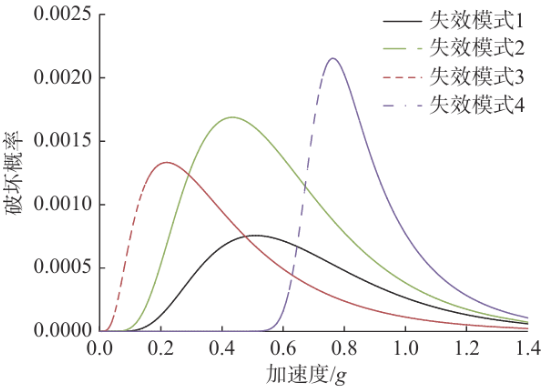


**Figure 7: Damage Probability Of Four Failure Modes(1st)**

***IDA Incorporating Multiple Failure Modes & Earthquake Probability In Specific Regions For A 9-Story Frame Isolated Structure***

In addition, Liu et al. (2023) have also applied the IDA method to another practical 9-story frame structure (as shown in Figure 8, Figure 9, Figure 10 & Figure 11), which combines multiple failure modes and earthquake probabilities. Four failure modes are adopted in this analysis (see FIG. Y), with the fourth one being excluded due to its low probability. After calculating the fragility curves for the three modes of failure (refer to FIG. X), the damage probability for each mode is generated by incorporating the seismic hazard rate in a specific area over a 50-year period (refer to FIG. X). They have determined that, in comparison to other factors contributing to failure, this model should prioritize the control of horizontal displacement of isolators as a means of reducing the likelihood of collapse.

As such, two design optimization schemes have been proposed: (1) increasing the diameter of isolators and (2) augmenting the ratio of tensile steel reinforcement at the end of first-layer beams to 1.5% and elevating concrete grade to C40, thus to improve the stiffness of the bottom floor and enhance the ductility of beam-column joints (Liu et al., 2023). With the addition of the unchanged scheme, there are now three schemes. By conducting further analysis, a

Journal of Information System and Technology Management
JISTM
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Volume 10 Issue 39 (June 2025) PP. 135-151
DOI: 10.35631/JISTM.1039009

comparison diagram illustrating the failure probability between the unchanged scheme and Scheme 2 was obtained. The results indicate the failure probability of failure mode 2 in Scheme 2 decreases by 47.3%, as shown in Figure 12 (Liu et al., 2023). The weakest failure mode optimization method has thus been demonstrated to significantly enhance the safety level of the structure in a prompt manner.

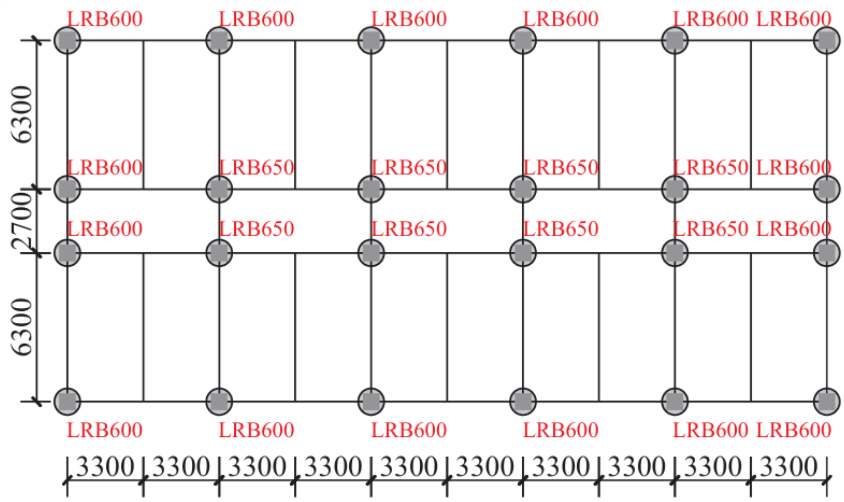


**Figure 8: Structural Plan For A 9-Story Practical Framework Structure In mm**

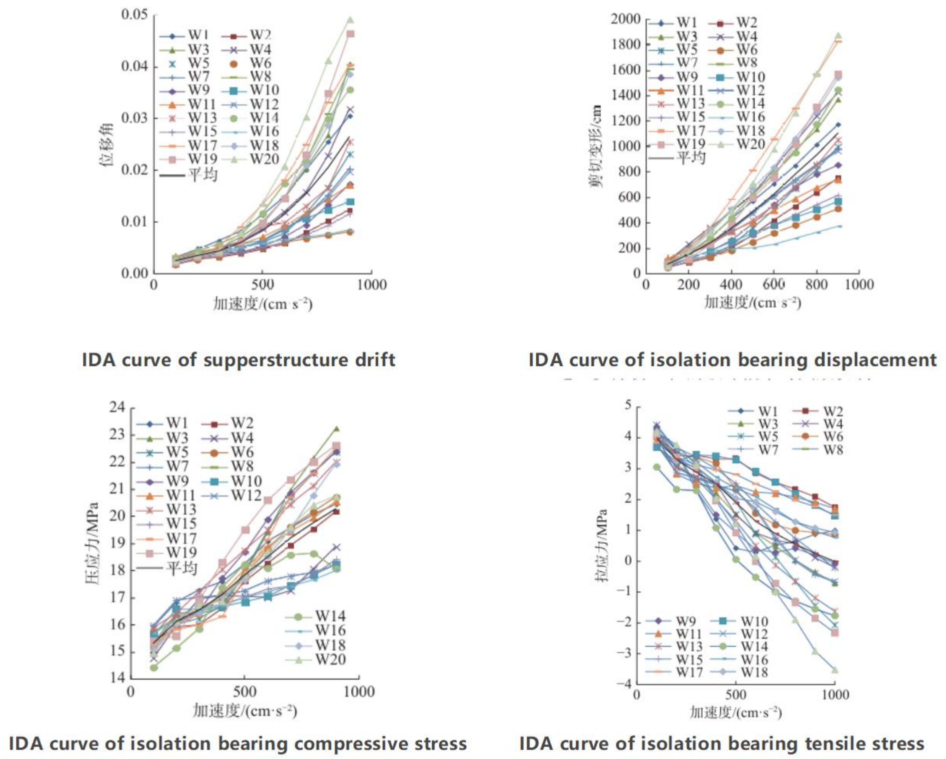


**Figure 9: IDA Curves Of Isolators Under Different Failure Modes In The 9-Story Structure**

Journal of Information System and Technology Management
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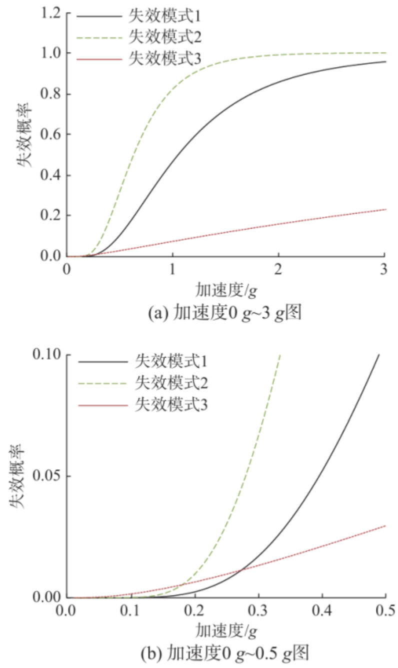


**Figure 10: Fragility Curves Of Top Three Failure Modes(2nd)**

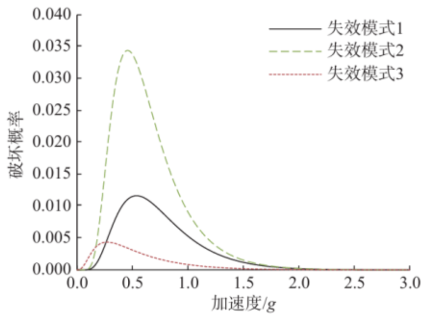


**Figure 11: Damage Probability Of Top Three Failure Modes(2nd)**

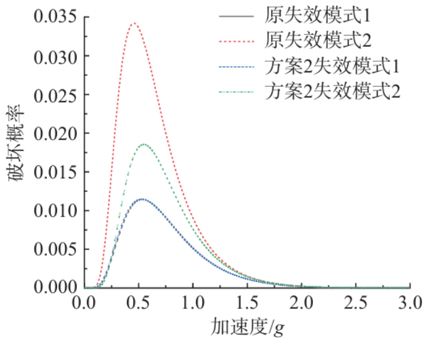


**Figure 12: Damage Probability Of Scheme 2 & Unchanged Scheme**

**IDA & GIS Techniques**
IDA can also be combined with ArcGIS techniques; this combined method will be preferred to apply in predicting the seismic risks of both roads and structures.

Journal of Information System and Technology Management
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***IDA & GIS Applied To Roads In Penang***

In the research of Maissi et al. (2022), the Intrinsic seismic vulnerability index (ISVI, mainly including IDA) method was mainly applied to the safety assessment of roads in earthquakes. The subject of their research are the roads of Penang in Malaysia. The vulnerability of the structure is calculated by taking the height of the embankment, pavement strength, road width and soil type as influencing factors. Then, those roads can be divided into safe, moderately resistant and low resistant categories. The calculated results were combined with ArcGIS, and the Accessibility Index of the road can be calculated through the cost-distance analysis and marked on the map. In this way, the Accessibility Index of the road in the case of an earthquake can be clearly displayed on the map. This innovative combined method provides information for risk management decisions. For example, based on this, emergency escape routes after an earthquake and sections that need to be strengthened and repaired in normal times can be planned. In addition, this study also found that the embankment is the most crucial factor affecting the seismic vulnerability of the road, followed by the road width, soil type and pavement strength are not effective parameters. Finally, this study also clarified the correlation between the physical assessment method and the accessibility index, making the conclusion more accurate.

***IDA & GIS Applied To Structures In Penang***

Yin et al. (2022) employed the combination of the IDA method, the vulnerability calculation, the seismic resilience index and the GIS to study the performance of the RC structures that have been built in Malaysia under earthquakes. Firstly, Yin et al. (2022) selected 25 structures located in Penang as the research objects (12 low-rise buildings, 7 mid-rise buildings, and 6 low-rise buildings). Modelling is carried out in accordance with European norms such as Eurocode 1, 2 and 8, and the Finite Element (FE) platform, such as ETABS, was used. After that, Yin et al. (2022) analyzed these models, calculated the fragility curves and vulnerability curves of the structure using the IDA method, and finally obtained the functionality curves. During the research process, Yin et al. (2022) found that the SRI of low-rise buildings was actually lower than that of high-rise buildings. Most importantly, they used GIS to display the SRI values of houses of different heights in this area on the map, providing support for subsequent decisions on risk management in combination with other engineering data such as the road accessibility index. These risk-related decisions can include evacuation routes, rescue routes, loss assessment, repair and reinforcement of houses and roads, etc. The combination of IDA's probability-based analysis method and the application of GIS can visualize the threat of earthquakes to buildings. The conclusions obtained from the calculation are no longer limited to a single structure itself, but can provide an overview of the performance of the entire community or even the city under earthquakes.

***IDA & GIS Applied To Structures In Dubai***

This article by Hamaydeh et al. (2021) provides data on the seismic risk analysis of multi-storey buildings in Dubai and combines GIS software to mark the seismic risks on the map. A total of 5 multi-story structures were selected. They modelled them using the IDARC software and applied 44 far-field seismic records as required by FEMA-P695, and calculated their vulnerability curves using the IDA method. Finally, these data are displayed on a map using GIS as fatalities per square kilometre. This article is based on data and has no definite conclusion. However, its approach of combining DIA with GIS and presenting maps with estimated number of fatalities/km^2 provides inspiration for further studies.

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### *IDA & GIS Applied To Structures In Croatia*

Nikolic et al. (2025) evaluated the seismic vulnerability of the Croatian coastal urban area, particularly the buildings in Kastela town. Specifically, they selected 18 structures of Kastela town and conducted modeling and analysis using 3MURI software. Combined with the method of IDA, their seismic vulnerability was obtained. GIS is widely applied in this study. Besides marking the seismic risks of these structures at different years on the map in different colors, the risks brought by the earthquake to electricity supply, water supply, drainage, road network, construction density, etc. are also marked in the same map. They used the PROMETHEE method to organize the risks of these earthquakes to different constructions in the same map, forming an overall earthquake risk map. This research holds significant value for the decision-making of emergency management and future urban planning.

## ANN Based IDA Method

The application of Artificial neural network (ANN) in IDA have been studied by many researches, especially those used in bridges and tunnels.

### *ANN Based IDA In Bridges*

Liu et al. (2022) studied the simplified method of calculating the seismic vulnerability of multi-span concrete bridges using the IDA through the artificial neural network (ANN) method, which greatly saved the calculation time. Specifically, Liu et al. (2022) modelled 516 Bridges using OpenSees and then took PGA as the seismic intensity index. Taking the limits of pier column curvature, bearing deformation and abutment deformation as the basis for judging structural failure, the IDA analysis of the structure was carried out. The results of IDA analysis were used as the input and output parameters of ANN, and a database was established.

Take the training set, which accounts for 80% of this data, the validation set, which accounts for 10%, and the test set, which accounts for 10%. In the training set, which accounts for 80%, the ANN model learns from the experience of these data and can obtain basic features and model functions. Rich data can ensure the accuracy of the model, that is, it can accurately reflect the relationship among bridge characteristics, limit values and results. In the Validation set accounting for 10%, the ten-fold cross-validation method was applied. This method divides the data into 10 subsets and uses one of the subsets to verify the accuracy of the model trained from the other data. In this step, the validation set will participate in the adjustment of the model multiple times to find the best model. For the test set accounting for 10%, they use it to conduct the final evaluation of the established model. During this process, the models that have been formed will no longer be adjusted. Finally, they compared the results calculated by the ANN model with those calculated by IDA and found that they had good consistency. Furthermore, they mentioned that using the model trained by ANN for calculation could "directly provide" the required conclusion, while using the IDA analysis method for calculation (with an Inner Core PC with a 2.5GHz i5 CPU) required around 300 hours. This proves the practicability of using the ANN generation model to simplify IDA calculations.

### *ANN Based IDA In Tunnels*

In this article, Huang et al. (2022) uses the method combining ANN and IDA to evaluate the tunnels in soft soil. Specifically, they established a model of the soil-tunnel system using ABAQUS and analyzed this model. The data corresponding to its Seismic Intensity Measure (XIM) and Damage Measure (XDM) (XIM-XDM) were obtained. The 240 calculated XIM-XDM data were divided into the training set accounting for 80% and the test set accounting for

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20%. Then, an ANN model is established based on multilayer perceptron (MLP) and trained using feed-forward back-propagation (BPP). Finally, the trained model is evaluated using the test set, which accounts for 20%.

Huang et al. (2022) found that: (1) For this ANN model, this ANN model contains a hidden layer using the LOGSIG function and an output layer using the PURELIN function. Additionally, the algorithm used for training is Levenberg-Marquardt, and the neurons in the hidden layer are ultimately determined to be two; (2) In traditional IDA calculations, the strength index XIM and the damage index XDM are usually assumed to have a linear relationship in the logarithmic space. However, the model calculated based on ANN can consider a nonlinear relationship, and the calculated XDM is more accurate; (3) Peak ground velocity (PGV), as the seismic intensity measure, can most effectively reflect the seismic response endured by the structure; (4) The vulnerability curves calculated based on the ANN model were compared with those calculated by the traditional IDA method, and it was found that the two were similar. Moreover, the new method can replace the traditional time-consuming finite element modeling and can conduct a large number of vulnerability analysis simulations within a few minutes.

**Discussion**

The analysis of Incremental dynamic analyzes mainly includes three elements:
Engineering Demand Parameters (EDP/DM). For complex structures, the selection of DMs will be more complex due to the consideration of various failure modes. For example, the failures of seismic isolation structures can be due to the excessing tension, compression and displacement of isolators, as well as the excessive story drift of the superstructure. Although the former is more likely to be the decisive factor, all potential failure modes should be analyzed.

Intensity measures (IMs). The most of studies adopt story drift for IDA in ordinary structures, however for IM, wider range of parameters is considered, including the second period acceleration, the magnitude of the earthquake and the epicentral distance.

Ground motion waves. For the selected earthquake, the earthquake that matches the location of the structure will be selected. Sometimes, some studies also select specific near-field or far-field earthquakes according to the distance between the location of the structure and the seismic fault zone, which can better reflect the characteristics of the structure during earthquakes.

Under normal circumstances, IDA only obtains the collapse probability of the structure under a certain earthquake intensity. However, if considering the earthquake probability of the region, for example, to take account of the likelihood of the earthquake occurrence with intensity of 8 degree in the next 50 years in this region, then the actual seismic ability of the structure can be more effectively assessed. In addition, many complex structures exhibit various failure modes, and the fragility curves of their components should be considered. The usual logic is that a structure is defined as collapse when any of its critical components completely fail.

Although different studies have used various combinations of IMs, the use of different combinations leads to conclusions with varying levels of accuracy. One research gap that could be addressed is the lack of comparative studies on identifying the most accurate combination of IMs for IDA to seismic isolation structures. Additionally, another gap of future study pertains to the lack of research on IDA for seismic isolation structures that incorporates multiple earthquake IMs, earthquake probabilities specific to certain regions, and various failure models.

Through the review of GIS in IDA process and ANN based IDA methodologies, we found that the combining application of ANN based IDA method with GIS system is rarely studied. This could be another research areas for the future.

## Conclusion

This article first reviews the applications of Incremental Dynamic Analysis (IDA) in various engineering projects, followed by introducing some of the studies that have improved the accuracy of the IDA method, especially through considering various earthquake intensity measures. Typically, this paper focuses on a study that incorporates both the multiple failure modes of seismic isolation structure and the earthquake probability of the region where the structure is located. In addition, the ArcGIS & IDA combined applications and the ANN based IDA methodologies are reviewed. Through a comprehensive analysis and discussion of those literatures, three future research domains have been identified.

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