Fuzzy Logic Support System for Predicting Building Damage Due to the Association of Three Parameters of Pipeline Failure

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Abstract: In this study, a fuzzy logic decision support tool (FLDST) was constructed for three parameters of sewer pipeline failure to get the total influence of these parameters on building damage. The effect of the shape and number of membership functions was investigated. The well-known computer program "ANSYS+ CivilFEM" is used to investigate the influence of pipeline settlement, settlement location, building location with respect to pipeline, soil stiffness and burial depth on the building damage category. The results were implemented in a fuzzy based assessment system for reinforced concrete building structures to evaluate the damage category of buildings due to the association of three parameters of pipeline failure. A criterion to define membership functions, their shape and their number, for each parameter as well as the rule base covering the whole range of all parameters was described. Several examples were run by MATLAB and were validated by ANSYS to evaluate the FLDST in predicting the damage category of building. The category of damage based on FLDST was consistent with that obtained from ANSYS calculations with great efficiency and time saving.

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1. Introduction

The influence of pipeline failure on adjacent structures is very important to investigate in urban areas due to high reconstruction and maintenance costs. In this study, a finite element program "ANSYS+ Civil FEM"[1], which takes into consideration the elasto-plastic behavior of soil, the pipeline failure mechanisms, and the presence of the structure, was employed to investigate the general failure mechanisms of soil- structure interaction. This analysis produced a large amount of output data. **Metwally** [2] has evaluated the damage assessment of building due to the deterioration of pipelines and how the pipeline failure can induce vertical settlement of the foundation of the adjacent structure, which results in noticeable damage of buildings. The damage categories are based directly on the descriptions of damage provided in Table 1 by **Burland** [3], **Boscardin and Cording** [4]. The output settlement underneath adjacent buildings was used to calculate the cumulative tensile and principal crack widths. The tensile cracks were calculated at the first bay of building (from 5.0 to 10.0 m), the nearest one to the pipeline failure.

The calculation of damage category by "ANSYS+CivilFEM" software is time consuming and it doesn't cover the entire operation range. Therefore, an expert system was introduced to predict the degree of damage for different parameters of pipeline failure.

Fuzzy logic is one of the most important applications of expert systems in civil engineering. The fuzzy set theory was developed by **Zadeh** [5]. It has been used for optimization of the active control of civil engineering structures [6-8].

In this study, a fuzzy rule-based decision support system is developed to determine the damage category of a building for a wide range of different parameters, depending on differential settlement underneath the building crack width and number of cracks obtained from ANSYS model. This was accomplished for two different parameters [9] and will be extended in this study for a parametric study for different cases of three parameters of failure acting at the same time. The effect of the shape and number of membership functions was discussed briefly to attend the required accuracy of results.

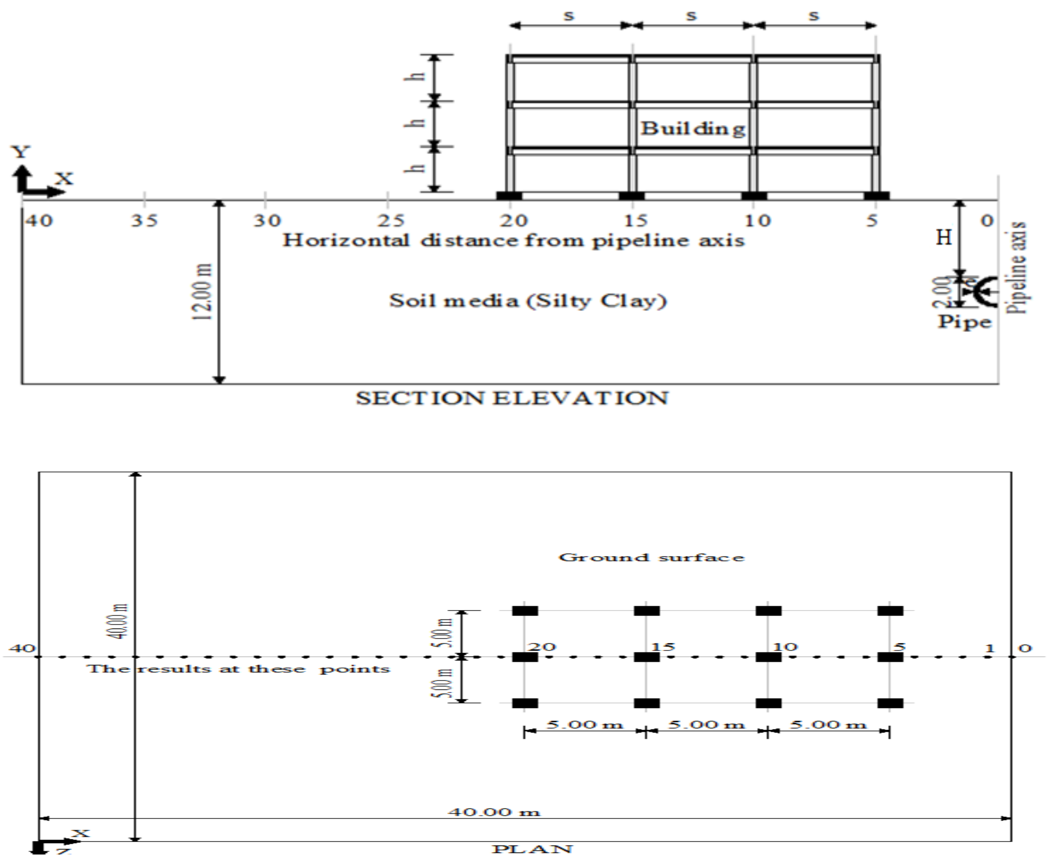
2. Numerical model

Three-dimensional geometric model [9] was used to quantify the interaction between sewer pipeline, soil and building in the coupled analysis (Fig.1). The numerical values in this parametric study are deduced from the practical observations of the deteriorated sewer pipes within the Greater Cairo sewer network [2]. The pipeline comprises 20 pipe segments; the length of each is 2 meters, where the connections between them are contact element. The type of contact element of pipes connection was taken as "no separation contact element". In this "no separation contact" element, the two contact surfaces “target and contact surfaces” are tied, although sliding is permitted.

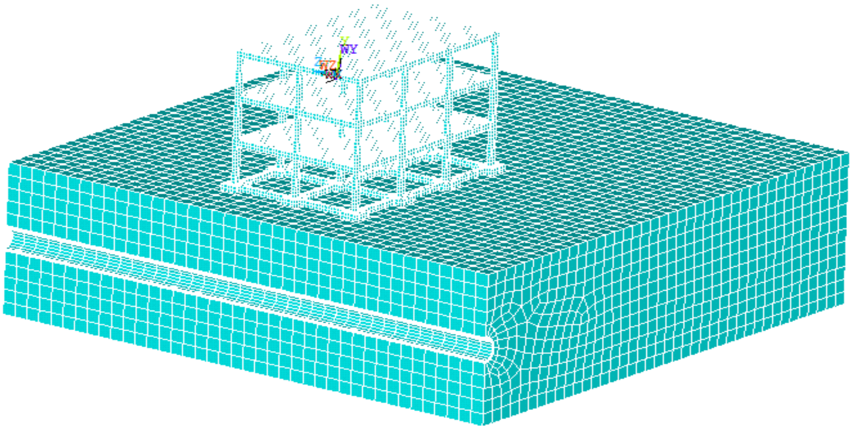
Table1. Building damage classification after Burland [3] and Boscarding and Cording [4].

Risk Category	Degree of Damage	Description of Typical Damage	Approximate Crack Width (mm)
0	Negligible	Hairline cracks	Null
1	Very Slight	Fine cracks easily treated during normal decoration	0.1 to 1
2	Slight	Cracks easily filled. Several slight fractures inside building. Exterior cracks visible	1 to 5
3	Moderate	Cracks may require cutting out and patching. Door and windows sticking	5 to 15 or a number of cracks > 3
4	Severe	Extensive repair involving removal and replacement of walls, especially over doors and windows. Windows and door frames distorted. Floor slopes noticeably.	15 to 25 but also depends on number of cracks
5	Very Severe	Major repair required involving partial or complete reconstruction. Danger of instability.	> 25 but depends on number of cracks

The pipeline is encased in isotropic, continuous, homogeneous, and isotropic soil mass. Table 2 illustrates the used data. The frictional slip is allowed between pipe and soil. The column's spacing of building in the two directions s = 5.0 m, and the height of each level h = 3.0 m. The properties of building materials taken for deformation and failure prediction calculations are shown in Table 3. The contact element between the building foundation and the soil was taken rough element. In this element, the two contact surfaces are not slipping, although separation is permitted.



(a) Geometric model.



(b) FEM model.
Fig.1. Numerical model [9].

Table 2. Soil and pipeline properties [2].

Soil properties		Pipeline properties	
Soil elastic modulus E_s	2000 t/m^2	Pipe diameter D (interior)	2.00 m
Soil Poisson's ratio υ	0.35	Wall thickness of concrete e	0.20 m
Soil cohesion C	2.00 t/m^2	Pipe length Lp	2.00 m
Angle of internal friction ϕ	30^o	Number of pipes in pipeline	20 pipes
Density of soil over pipe γ	1.85 t/m^3	Concrete elastic modulus E_c	3.5E6 t/m^2
Soil height above crown H_t	5.0 m	Concrete Poisson's ratio υ_c	0.20
μ (Between soil& pipes)	0.32	μ (Between pipes segments)	0.60

Table 3. Structural material data [2].

Properties	Building elements
Density γ (t/m^3)	2.5
Compressive stress* f_c (kg/cm^2)	90
Tensile stress* f_t (kg/cm^2)	10.8
Shear stress* q (kg/cm^2)	19
Young's modulus E (t/m^2)	2.1E06
Poisson's ratio ν	0.20
compressive strain* ε_c	0.003
tensile strain* ε_t	0.003
Shear strain* ε_s	0.003

*Allowable stress or strain

3. Fuzzy Expert System Model to Evaluating the Damage Category of building

A fuzzy expert system shown in Fig. 2 consists of four components namely, the fuzzifier, the inference engine, the defuzzifier, and a fuzzy rule base. During fuzzification, crisp inputs are converted into linguistic values and are related to the input linguistic variables.

A membership function must vary between 0 and 1. The function itself can be an arbitrary curve whose shape can be determined based on different criteria as simplicity, convenience, speed, and efficiency. The membership function shapes used in this paper are Triangular, Trapezoidal, Gaussian, Z curve and S Curve Membership Function. The membership function shapes and numbers are determined by trial and error to find the most suitable and accurate one for the specific case studies.

Subsequently, as the fuzzification process is completed, the inference engine refers to the fuzzy rule base containing fuzzy IF-THEN rules to deduct the linguistic values for the intermediate and output linguistic variables. When the output linguistic measures are obtainable, the defuzzifier produces the final crisp values from the output linguistic values.

This study aims to construct a decision support system for damage category of reinforced concrete building structures based on numerical solutions obtained from ANSYS results for each parameter at a time and combines them to get the extent of damage due to three parameters at the same time. Three different variables that have influence on building damage were used as inputs for fuzzy system. Then a procedure using the fuzzy inference methodology was developed to determine the output of a fuzzy system.

The rule-base is the main part of the FLDST. It is formed by a family of logical rules that describes the relationship between the three inputs and the one output of the fuzzy system. In this paper three cases were studied to represent a parametric study for the proposed method.

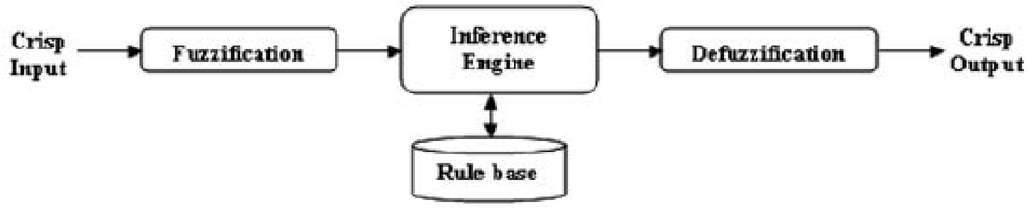


Fig. 2. Fuzzy expert system model.

4. Inputs of fuzzy logic

The numerical values used in the parametric study of this part are deduced from practical observations of the deteriorated sewer pipes within the Greater Cairo sewer network [2].

4.1 Pipeline settlement

Settlement in the pipelines and its effect on building damage is explained by considering different values of vertical settlement in the middle six pipe segments; 1% D, 3% D, 5% D, 8% D and 10% D where D is the pipe diameter as shown in Fig. 3.

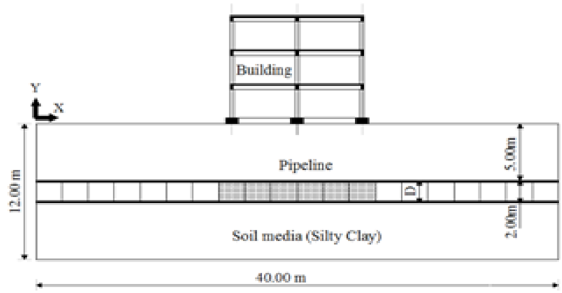


Fig. 3. Location of pipeline settlement.

4.2 Settlement location

Settlement location relative to the building in the pipelines is explained by considering three different horizontal locations of settlements as shown in Fig. 4. The pipeline settlement value was taken 5% D where D is pipe diameter.

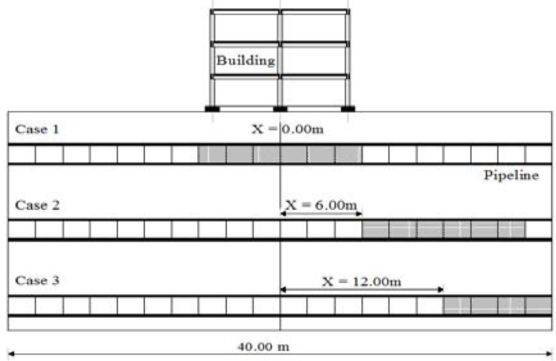


Fig. 4. Location of vertical settlement of pipeline with respect to building.

4.3 Burial depth

The influence of burial depth is demonstrated by considering three heights of soil above the crown of the pipe; 3, 5, and 7 m. Tables 2, 3 give the properties of silty clay soil, pipe, and building respectively. The settlement value was fixed as 5% D (D is pipe diameter) in the middle 6 pipe segments.

4.4 Building location

The influence of building location relative to pipeline settlement is demonstrated by considering three different locations from the nearest side of building relative to the centerline of the pipeline (XB); 3, 5, and 7 m as shown in Fig. 5. The settlement value was taken 5% D (D is pipe diameter) in six pipe segments at (X=0.00m).

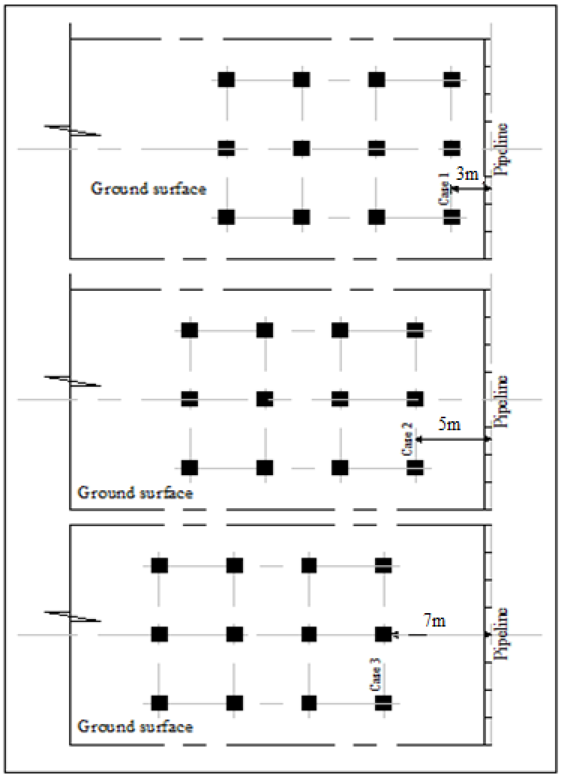


Fig. 5. Different building location with respect to pipeline.

4.5 Soil stiffness changing above pipeline

The deterioration of pipeline may occur due to soil stiffness changing above pipeline. As shown in Fig. 6, the width of the part of soil considered above the pipeline is equal to the burial depth from each side of vertical axis of pipeline. The soil stiffness changing above pipeline is explained by considering three values of soil stiffness relative to the value of the existing soil stiffness; 0.25E, 0.50E, and 0.75E (E is Young's modules of soil).

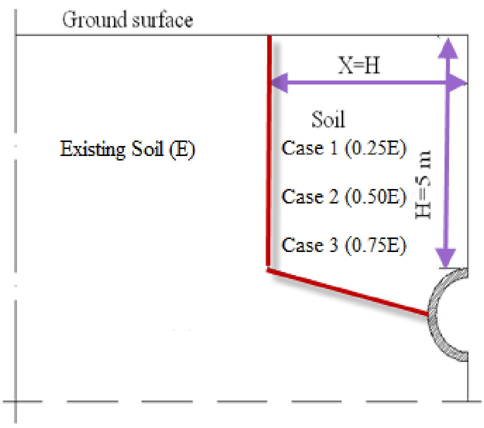


Fig. 6. Changing in soil stiffness above pipeline.

5. Three inputs – one output decision support tool

5.1 Case 1: Pipeline settlement with pipeline settlement location and building location

The inputs of this case are the Pipeline Settlement (P.St), the Settlement Location (St.L.x) and the Building Location (B.L). The data obtained from ANSYS describes the influence of pipeline settlement, settlement location and building location on the damage of building.

Fig. 7 illustrates the membership functions which are used in this case. The membership functions shapes are S, Z, Triangular, trapezoidal and Gaussian. Determining the shapes and numbers of membership functions are reached after many trial and error to find the most suitable and accurate one for the specific case study.

The first input of FLDST is chosen from 1%D to 10%D. Five Membership Functions (MFs) are chosen for the first input (pipeline settlement) as shown in Fig. 7.a. The linguistic terms for defining the membership functions are: (1%D), (3%D), (5%D), (8%D) and (10%D), where %D is the percentage of settlement occurring as a function of pipeline diameter. The first membership function is Z function, the second and fourth are triangular, the third trapezoidal and the fifth is S function. For each function different shapes were tried from triangular to Gaussian till we reach the most suitable one for each case. The number of functions for each parameter is increased till we reach the required accuracy. Five membership functions were good enough to give accurate results for most inputs but for outputs we use six membership functions since there are six category of damage according to Table 1. For all the next inputs, increasing the number of membership functions has more effect on the accuracy of results than changing the shape of functions but requires extensive mathematical operations.

The second input of FLDST is chosen from 0m to 12m. Five membership functions are chosen for the second input (settlement location). The linguistic variables of MFs defined as (0m), (3m), (6m), (9m), and (12m) as shown in Fig. 7b. The first one is Z function, the last one is S function while the inner three are triangular. The third input (building location) of FLDST is chosen from 3m to 7m. Five membership functions are chosen for the third input (building location). The linguistic variables of MFs defined as (3m), (4m), (5m), (6m), and (7m) as shown in Fig. 7c. The first one is Z function, the last one is S function while the inner three are Gaussian.

Six membership functions are used to represent the six linguistic variables of output (damage category of building). The name of six linguistic variables of output is: NEG is negligible, VSL is very slight, SL is slight, MOD is moderate, SV is severe and VSV is very severe as shown in Fig. 7d. The first one is Z function, the last one is S function while the inner four are triangular.

The rule base was constructed based on data obtained from ANSYS results after solving several cases. A sample of these rules that cover the whole range of the three parameters is introduced in Table 4.

Fig. 8 illustrates in three dimensions one of the rule base surfaces for parameters in case 1. The damage category is determined for different values of pipeline settlements as well as for different pipeline settlement location at fixed value of building location. We can deduce from this figure that pipeline settlement has more impact on building damage than settlement location.

Huge number of examples was run by ANSYS for different pipeline settlement along with different pipeline settlement locations and different building locations to cover the whole range of the three parameters. The category of damage was identical to the proposed method. Table 5 illustrates sample of several examples from **MATLAB** [10] and was validated by ANSYS computer program to validate and evaluate the proposed FLDST in predicting the damage category of building. The degree of potential damage based on FLDST is consistent with that obtained from ANSYS calculations. As shown in Table 5, the FLDST has the ability to cover the entire range of pipeline settlement, pipeline settlement locations along with building location. Now we can use it to evaluate damage category of building at any value of the entire range of inputs with accurate results without using additional ANSYS program calculations.

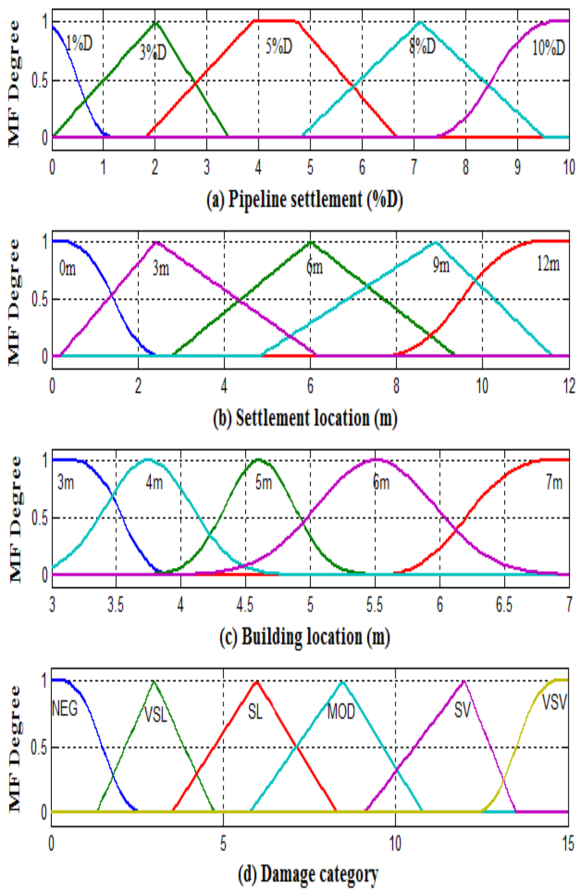


Fig. 7. Membership functions inputs and output of FLDST in case 1.

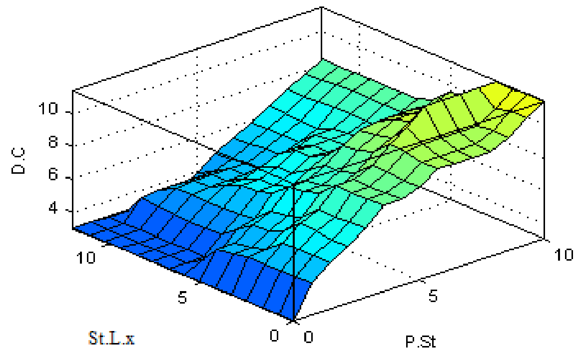


Fig. 8. Damage category surface for case 1.

5.2 Case 2: Pipeline settlement with building location and burial depth

The inputs of this case are the Pipeline Settlement (P.St), the Building Location (B.L) and the burial depth (B.D). The data obtained from ANSYS describes the influence of pipeline settlement, building location and burial depth on the damage of building.

Figure 9 illustrates the membership functions which are used in this case. The same criteria used in case 1 to select the shapes and numbers of membership functions was used in case 2. The universe of discourse for the first input (pipeline settlement) of FLDST is chosen from 1%D to 10%D. Five Membership Functions (MFs) are chosen for the first input (pipeline settlement) as shown in Fig. 9a. The linguistic terms for defining the membership functions are: (1%D), (3%D), (5%D), (8%D) and (10%D), where %D is the percentage of settlement occurring as a function of pipeline diameter. The first one is Z function, the last one is S function while the inner three are Gaussian. This was suitable for all other inputs and output of case 2.

Table 4. Fuzzy rule base for case 1.

Settlement Location		Pipeline Settlement 1%D	3%D	5%D	8%D	10%D	Building Location
	X= 0m	VSL	SL	MOD	SV	SV	XB=3m
	X= 0m	VSL	SL	MOD	SV	SV	XB=5m
	X= 0m	VSL	SL	MOD	MOD	SV	XB=7m
	X = 3m	VSL	SL	MOD	SV	SV	XB=3m
	X = 3m	VSL	SL	MOD	SV	SV	XB=5m
	X = 3m	VSL	SL	SL	MOD	SV	XB=7m
	X= 6m	VSL	SL	MOD	MOD	MOD	XB=3m
	X= 6m	VSL	VSL	SL	MOD	MOD	XB=5m
	X= 6m	VSL	VSL	SL	MOD	MOD	XB=7m
	X= 9m	VSL	VSL	MOD	MOD	MOD	XB=3m
	X= 9m	VSL	VSL	SL	SL	MOD	XB=5m
	X= 9m	VSL	VSL	SL	SL	MOD	XB=7m
	X=12m	VSL	VSL	SL	SL	MOD	XB=3m
	X=12m	VSL	VSL	VSL	SL	MOD	XB=5m
	X=12m	VSL	VSL	VSL	SL	MOD	XB=7m

Table 5. Evaluation and validation of potential damage for case 1.

	Pipeline Settlement		Settlement Location		Building Location		Damage Category
	2%D		3.0m		3.5m		SL
	4.5%D		6.5m		3.0m		MOD
	7.5%D		11.5m		6.5m		SL
IF	8%D	AND	9.5m	AND	5.0m	THEN	SL
	9.5%D		4.0m		4.5m		SV

The universe of discourse for the second input (building location) of FLDST is chosen from 3m to 7m. Five Membership Functions (MFs) are chosen for the second input (building location). The linguistic terms for defining the membership functions are: (3m), (4m), (5m), (6m) and (7m) as shown in Fig. 9b.

For the third input (burial depth) of FLDST, the universe of discourse is chosen from 3m to 7m. Five Membership Functions (MFs) are chosen for the third input (burial depth). The linguistic terms for defining the membership functions are: (3m), (4m),(5m), (6m) and (7m) as shown in Fig. 9c.

Five membership functions are used to represent the linguistic variable of output (damage category of building). For the values and kinds of the chosen parameters in case 2, the negligible category of damage was not used. The name of five linguistic variables of output is: VSL is very slight, SL is slight, MOD is moderate, SV is severe and VSV is very severe as shown in Fig. 9d.

The rule base was constructed based on data obtained from ANSYS results after solving several cases. A sample of these rules that cover the whole range of the three parameters is introduced in Table 6.

Fig. 10 illustrates in three dimensions one of the rule base surfaces for the three parameters in case 2. The damage category is determined for different values of pipeline settlements as well as for different burial depth at fixed value of building location. From this figure we can deduce that pipeline settlement has much more effect on building damage than burial depth of pipe that has low impact on building damage.

Table 6. Fuzzy rule base for case 2.

Building Location	Pipeline Settlement 1%	3%D	5%D	8%D	10%D	Burial Depth
XB=3m	SL	MOD	MOD	SV	SV	H_{soil}=3
XB=3m	SL	MOD	MOD	SV	SV	H_{soil}=4
XB=3m	VSL	SL	MOD	SV	SV	H_{soil}=5
XB=3m	VSL	SL	MOD	MOD	SV	H_{soil}=6
XB=3m	VSL	SL	SL	MOD	SV	H_{soil}=7
XB=4m	SL	MOD	MOD	SV	SV	H_{soil}=3
XB=4m	VSL	SL	MOD	SV	SV	H_{soil}=5
XB=4m	VSL	SL	MOD	MOD	SV	H_{soil}=7
XB=5m	SL	MOD	MOD	SV	SV	H_{soil}=3
XB=5m	VSL	SL	MOD	SV	SV	H_{soil}=5
XB=5m	VSL	SL	SL	MOD	SV	H_{soil}=7
XB=6m	VSL	SL	MOD	MOD	SV	H_{soil}=3
XB=6m	VSL	SL	MOD	MOD	SV	H_{soil}=5
XB=6m	VSL	SL	MOD	MOD	MOD	H_{soil}=7
XB=7m	VSL	SL	MOD	MOD	SV	H_{soil}=3
XB=7m	VSL	VSL	MOD	MOD	SV	H_{soil}=5
XB=7m	VSL	VSL	SL	MOD	MOD	H_{soil}=7

Huge number of examples was run by ANSYS for different pipeline settlement along with different burial depths and different building locations to cover the whole range of the three parameters. The category of damage was identical to the proposed method. Table 7 illustrates sample of examples run with MATLAB and validated by ANSYS computer program to evaluate the proposed FLDST in predicting the damage category of building. The degree of potential damage based on FLDST is consistent with that obtained from ANSYS calculations. So, we can use the FLDST to evaluate damage category of building at any value of the entire range of inputs with accurate results.

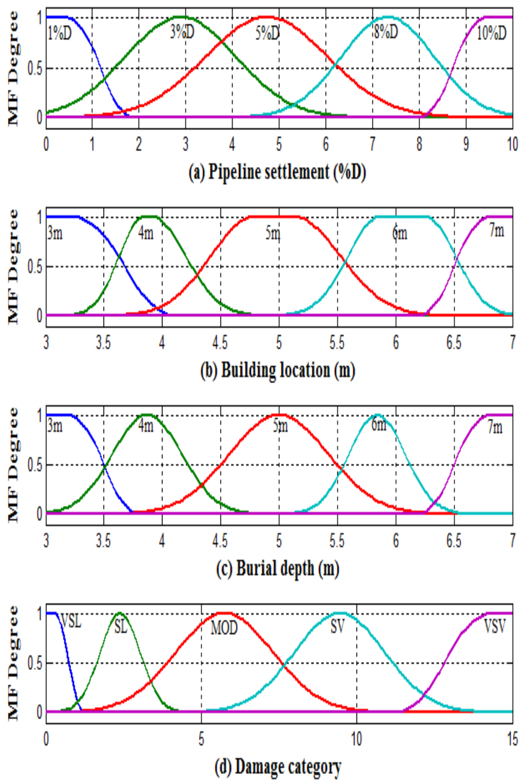


Fig. 9. Membership functions inputs and output of FLDST for case 2.

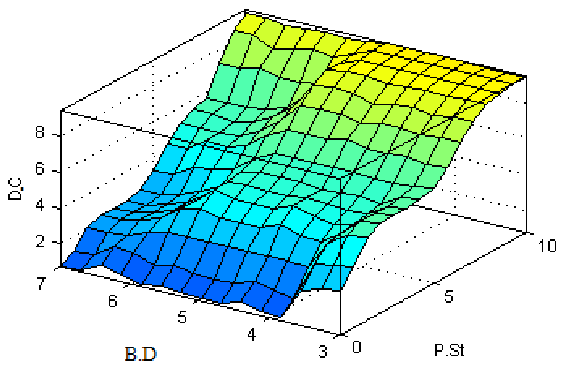


Fig. 10. Damage category surface for case 2.

Table 7. Validation of potential damage for case 2.

	Pipeline Settlement		Building Location		Burial Depth		Damage Category
	1.5%D		3.0m		3.5m		SL
	3.5%D		6.5m		6.0m		SL
IF	4.5%D	AND	4.0m	AND	3.5m	THEN	MOD
	8%D		5.5m		5.0m		SV
	9.5%D		6.0m		3.5m		SV

5.3 Case 3: Pipeline Settlement with soil stiffness and burial depth

The inputs of this case are the pipeline settlement (P.St), the Soil Stiffness (Soil Stif.) and the Burial Depth (B.D). The data obtained from ANSYS describes the influence of pipeline settlement, soil stiffness and burial depth on the damage of building. The same criteria used in case 1 to select the shapes and numbers of membership functions was used in case 3. Five Membership Functions (MFs) are chosen for the first input (pipeline settlement) as shown in Fig. 11.a. The linguistic terms for defining the membership functions are: (1%D), (3%D), (5%D), (8%D) and (10%D), where %D is the percentage of pipeline settlement as a function of pipe diameter. The first membership function is Z function, the second and fourth are triangular, the third trapezoidal and the fifth is S function.

For the second input (soil stiffness) of FLDST, the universe of discourse is chosen from 0.25E to 0.75E. Five membership functions are chosen to represent linguistic variables of MFs and it's defined as (0.25E), (0.40E), (0.50E), (0.60E) and (0.75E) as shown in Fig. 11b. The first membership function is Z function, the inner three are Gaussian and the fifth is S function. The universe of discourse for the third input (burial depth) of FLDST is chosen from 3m to 7m and it's defined as (3m), (5m) and (7m) as shown in Fig. 11c; all of them are trapezoidal functions.

Six membership functions are used to represent the linguistic variable of output (damage category of building) and they are defined as NEG is negligible, VSL is very slight, SL is slight, MOD is moderate, SV is severe and VSV is very severe as shown in Fig. 11d; The first membership function is Z function, the inner three are Gaussian and the fifth is S function.

The rule base was constructed based on data obtained from ANSYS results after solving several cases. A sample of these rules that cover the whole range of the three parameters is introduced in Table 8.

Fig. 12 illustrates in three dimensions one of the rule base surfaces introduced for the three parameters in case 3. The damage category is determined for different values of pipeline settlements as well as for different value of soil stiffness at fixed value of burial depths. This figure illustrates that pipeline settlement has more effect on building damage than soil stiffness.

Huge number of examples was run by ANSYS for different pipeline settlement and different soil stiffness above pipeline along with different burial depths to cover the whole range of the three parameters. The category of damage was identical to the proposed method. Table 9 illustrates sample of several examples from MATLAB that was validated by ANSYS computer program to validate the proposed FLDST in evaluating the damage category of building. The degree of potential damage based on FLDST is consistent with that obtained from ANSYS calculations. As shown in Table 9, the FLDST has the ability to cover the entire range of pipeline settlement and soil stiffness above pipeline along with different burial depth. Now we can use it to evaluate damage category of building at any value of the entire range of inputs with accurate results without using ANSYS program calculation

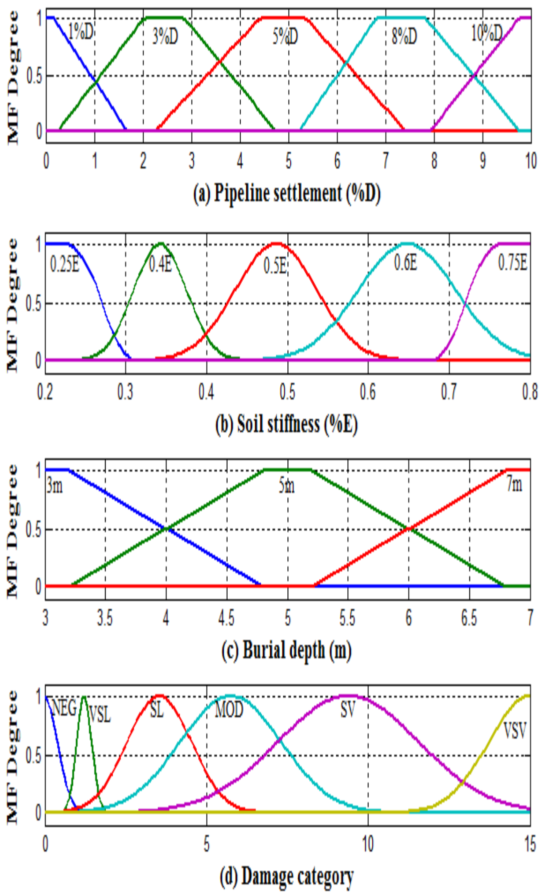


Fig. 11. Membership functions of FLDST for case 3.

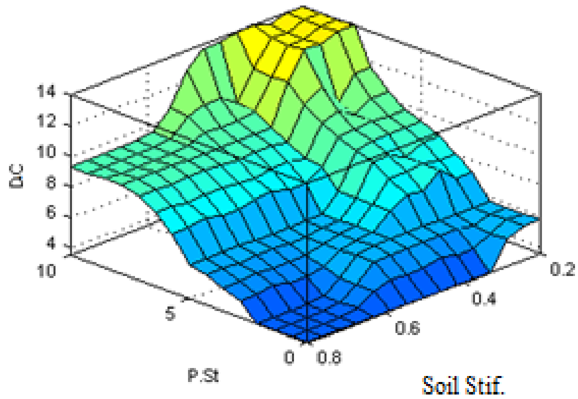


Fig. 12. Damage category surface for case 3.

Table 8. Fuzzy rule base for case 3.

Soil Stiffness	Pipeline Settlement 1%D	3%D	5%D	8%D	10%D	Burial Depth
0.25E	MOD	SV	SV	VSV	VSV	H_{soil}=3m
0.40E	MOD	MOD	SV	VSV	VSV	H_{soil}=3m
0.50E	SL	MOD	SV	VSV	VSV	H_{soil}=3m
0.60E	SL	MOD	MOD	SV	VSV	H_{soil}=3m
0.75E	SL	MOD	MOD	SV	SV	H_{soil}=3m
0.25E	MOD	MOD	SV	VSV	VSV	H_{soil}=5m
0.40E	SL	MOD	SV	VSV	VSV	H_{soil}=5m
0.50E	SL	MOD	MOD	SV	VSV	H_{soil}=5m
0.60E	SL	SL	MOD	SV	SV	H_{soil}=5m
0.75E	SL	SL	MOD	SV	SV	H_{soil}=5m
0.25E	SL	MOD	MOD	SV	SV	H_{soil}=7m
0.40E	SL	SL	MOD	MOD	SV	H_{soil}=7m
0.50E	SL	SL	MOD	MOD	SV	H_{soil}=7m
0.60E	VSL	SL	SL	MOD	MOD	H_{soil}=7m
0.75E	VSL	VSL	SL	MOD	MOD	H_{soil}=7m

Table 9. Evaluation and validation of potential damage for case 3

	Pipeline Settlement		Soil Stiffness		Burial Depth		Damage Category
	1.5%D		0.30E		3.5		MOD
	3%D		0.60E		6.0		MOD
IF	6%D	AND	0.55E	AND	3.5	THEN	SV
	8%D		0.45E		5.0		VSV
	9.5%D		0.75E		7.0		MOD

6. Conclusions

The purpose of this study is to present a method for evaluation of the damage category of building due to different three parameters of pipeline failure that occurred at the same time. A parametric study was introduced to different cases of three parameters of pipeline deterioration. The effect of shapes and numbers of membership functions on the accuracy of results was studied. Many conclusions can be reported from this research:

1. It was illustrated that changing the shape of membership function from triangular to trapezoidal, S, Z and Gaussian can improve the results depending on specific case study. Also, increasing the number of membership functions has more effect on the accuracy of results than changing the shape of functions but requires extensive mathematical operations.

2. The implementation of fuzzy logic in studying the effect of different pipeline deterioration parameters on the damage of nearby buildings, has emphasized the impact of each parameter with respect to the others:

a. It was shown that the value of pipeline settlement has the major impact on the damage of adjacent buildings, more than the settlement location, the building location, the burial depth and the soil stiffness.
b. We can also deduce that following the pipeline settlement, the settlement location has more effect on damage of nearby buildings than the building location.
c. The same can be shown for the burial depth that has more effect on damage than building location.
d. Finally, soil stiffness shows to be more effective in increasing damage category of buildings than burial depth.

3. Fuzzy logic results illustrated clearly that:

a. The potential damage of buildings **increases** due to the **increase** of pipeline settlement.
b. On the other hand, the potential damage of nearby building **decreases** due to the **increase** of: the pipeline settlement location from the considered section, the building location from the pipeline settlement and the soil stiffness above pipeline.

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