Chapter 3

RESULTS AND DISCUSSION

The training and testing results of network designed for estimating ground parameters of two-layer earth model was discussed in this chapter. It will begin with network for horizontal interface, and then followed by networks designed for dipping and irregular interface.

3.1 Network for two-layered dipping interface structure

Seven networks of two-layer architecture and seven networks of three-layer architecture were trained by 344 training data sets and tested by 35 testing data sets. The designed networks were trained and tested by both non-normalized data sets and normalized data sets. Training time, average MSE of all training data sets, and average MSE of all testing data sets were shown in Fig.3.1 to Fig 3.4.

Generally, the training time of each trained network increased with the number of neurons in the hidden layer because there were many parameters for adjusting in the training process. The training time of two-layer architecture networks trained by non-normalization data and normalization data were shown in Fig.3.1 a) and Fig.3.2 a) respectively. It could be observed that the training time of networks trained by non-normalization data sets was about four times less than that trained by normalization data sets. For the three-layer architecture networks, the training time of networks trained by non-normalization data sets was about two times less than that trained by normalization data sets, Fig.3.3 a) and Fig.3.4 a).

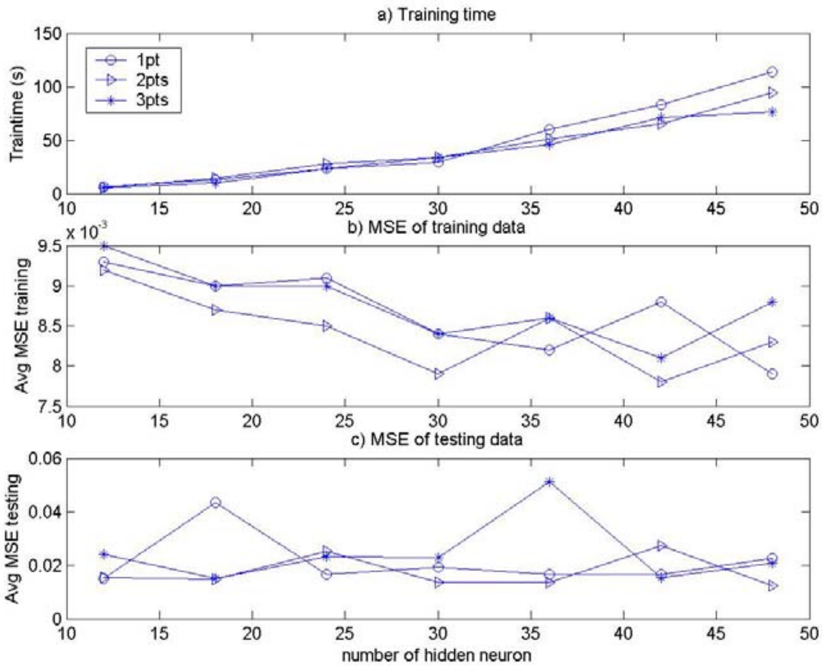


Figure 3.1 a) Training time, b) MSE of training data, and c) MSE of testing data of two-layer architecture network trained by non-normalization data

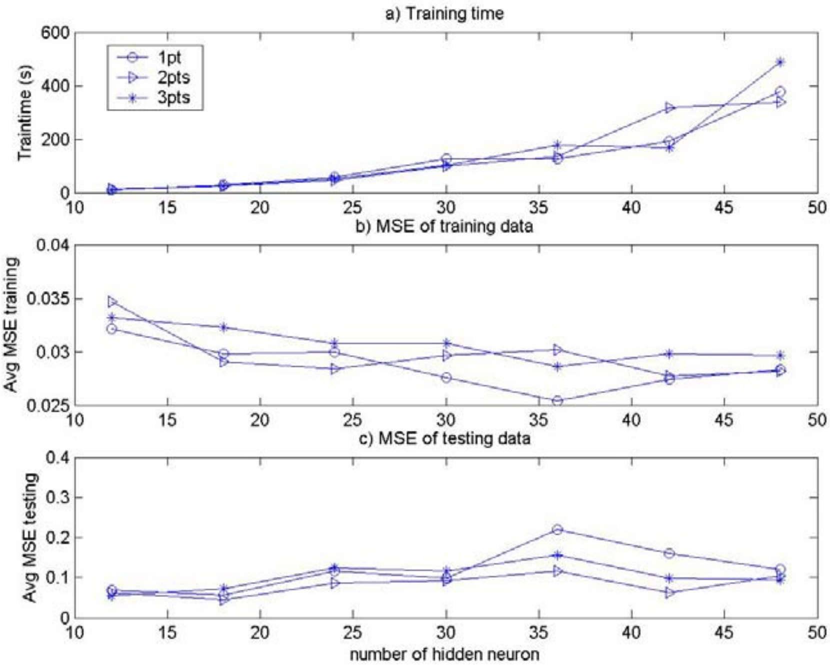


Figure 3.2 a) Training time, b) MSE of training data, and c) MSE of testing data of two-layer architecture network trained by normalization data

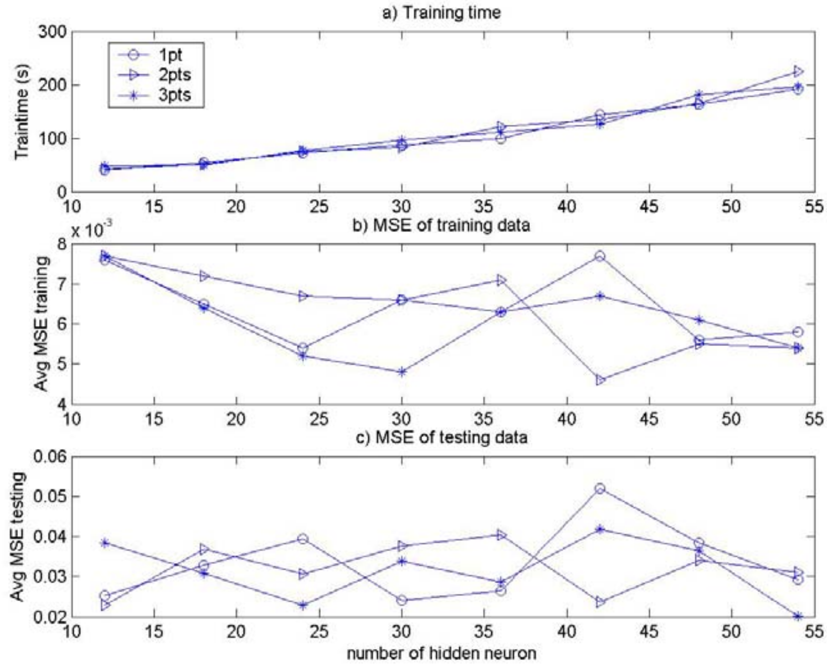


Figure 3.3 a) Training time, b) MSE of training data, and c) MSE of testing data of three-layer architecture network trained by non-normalization data

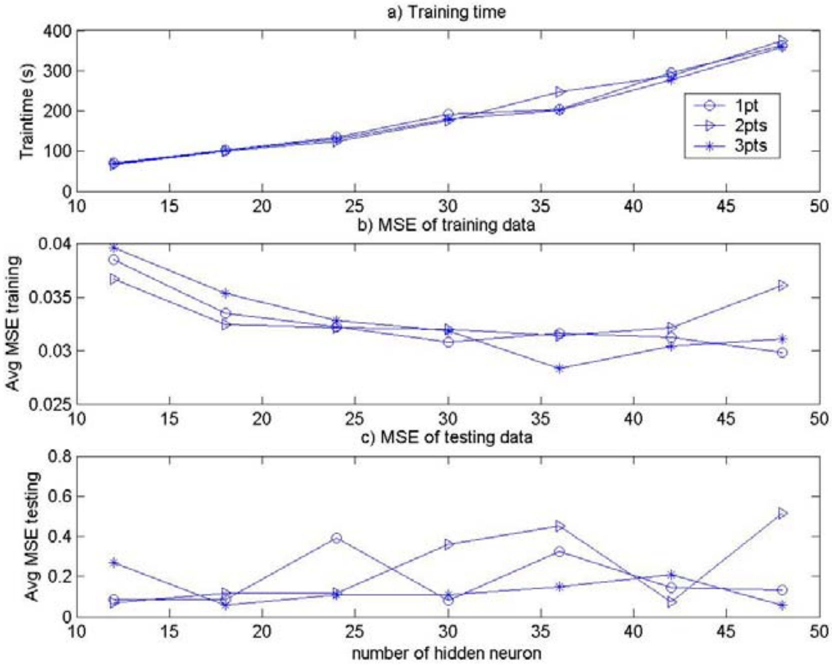


Figure 3.4 a) Training time, b) MSE of training data, and c) MSE of testing data of three-layer architecture network trained by normalization data

There was no direct correlation of between MSE of training data sets and number of neurons in hidden layer for both two-layer and three-layer architecture trained networks. The training MSE of network trained by normalization data sets was calculated after post-normalization process whereas the training MSE of network trained by non-normalization data sets was calculated from the outputs of the network directly. By this reason, the training MSE of network trained by normalization data sets was lager than the goal value, 0.01 and larger than the training MSE of network trained by non-normalization data sets.

The MSE of testing data sets also varied randomly with number of neurons in hidden layer. The testing MSE of network trained by normalization data was also larger than that of network trained by non-normalization data. The network which had minimum value of testing MSE will be chosen for estimating ground parameters. The predicted ground parameters of the chosen networks were shown in Fig.A1 to Fig.A12. The mean error and standard deviation of error were summarized in Table 3.1.

Table 3.1 Mean error and standard deviation of error of estimated ground parameters

Non-Normalization

Data Type	Network Architecture	Mean error (%)			Std error (%)		
		h1	V1	V2	h1	V1	V2
1-pt	24-24-3	-1.3	3.5	7.6	7.0	19.1	44.9
2-pt	24-30-3	-0.8	-0.6	1.7	5.3	8.0	10.3
3-pt	24-42-3	0.6	1.6	-0.5	3.7	11.6	8.0
1-pt	24-24-30-3	-1.0	-0.9	0.1	3.7	5.9	2.5
2-pt	24-24-42-3	1.1	-4.8	1.5	3.4	10.7	7.2
3-pt	24-24-54-3	0.3	-1.9	1.0	4.0	3.0	7.6

Normalization

Data Type	Network Architecture	Mean error (%)			Std error (%)		
		h1	V1	V2	h1	V1	V2
1-pt	24-18-3	-1.5	-1.9	-5.4	9.6	1.5	25.7
2-pt	24-18-3	-2.1	-2.4	2.6	9.5	9.1	29.0
3-pt	24-18-3	-1.9	-0.4	4.7	9.5	13.1	19.2
1-pt	24-24-30-3	-0.8	-0.8	-6.6	9.4	10.0	34.6
2-pt	24-24-42-3	2.0	1.0	5.7	17.3	8.6	48.3
3-pt	24-24-18-3	-2.1	-0.9	-4.0	12.3	8.4	16.5

For the predicted depth to interface, h_1, its mean error was less than 5 % in every network. Its standard deviation of error was less than 5 % for non-normalized data but greater than 5 % for normalized data.

For top layer velocity, V_1, its mean error was also less than 5 % in every architecture network. However its standard deviation of error was greater than 5 %, except that of the 24-18-3 architecture with 1-pt type of normalized data and the 24-24-54-3 with 3-pt type of non-normalized data.

For bottom layer velocity, V_2, its mean error was less than 10 % in every architecture network. Its standard deviation of error was less than 10 % for non-normalized data except that for the 24-24-3 with 1-pt data type. Its standard deviation of error was greater than 10 % in every architecture network for normalized data.

Therefore any network, either two-layer or three-layer network, could be used to determine the depth to interface with a very good accuracy, or with ±5 % error. It could be used to determine top layer velocity with ±10 % error and bottom layer velocity with ±20 % error. In addition, any type of data, either 1-pt, 2-pt, or 3-pt could be used to train and test the network.

3.2 The results of network for two-layer dipping interface structure

3.2.1 Non-separated network

3.2.1.1 t_{minus}-t_{plus} inputs

The trained networks were tested with three testing data sets of different dipping angle; 2.5, 8.5, and 14.5 degree. The depths to interface of receivers predicted by the networks were shown in Fig.A1 to Fig.A3. The predicted depths agreed very well with the target depth. However it could be observed that absolute values of error increased when the geophone was farther away from the first shot points. This was probably because most of training data were from an area close to the shot point where depth to interface was fixed. Mean error and standard deviation of error of all trained networks were summarized in Table 3.2.

Table 3.2 Mean error and standard deviation of error of estimated depth with non-separated networks of t_{minus}-t_{plus} inputs

Network	2.5 degree		8.5 degree		14.5 degree	
	mean error (%)	std error (%)	mean error (%)	std error (%)	mean error (%)	std error (%)
24-10-14	-0.7	2.5	-1.8	1.0	-0.2	0.6
24-5-14	-3.4	3.4	-2.0	1.3	-0.9	0.9
24-2-14	3.4	1.6	0.6	0.2	-0.5	0.2
24-10-5-14	1.2	2.4	-0.3	2.0	-2.1	1.0
24-10-10-14	2.7	1.7	0.8	0.8	0.2	0.4
24-5-10-14	2.1	1.5	0.2	0.5	-0.1	0.3

Both mean errors and standard deviation of error of estimated depths ranged from -5 % to 5 % for all architecture networks (Fig.3.5). It could be observed that the standard deviation of error decreased when the dipping angle increased but the mean error varied randomly with the dipping angle of interface.

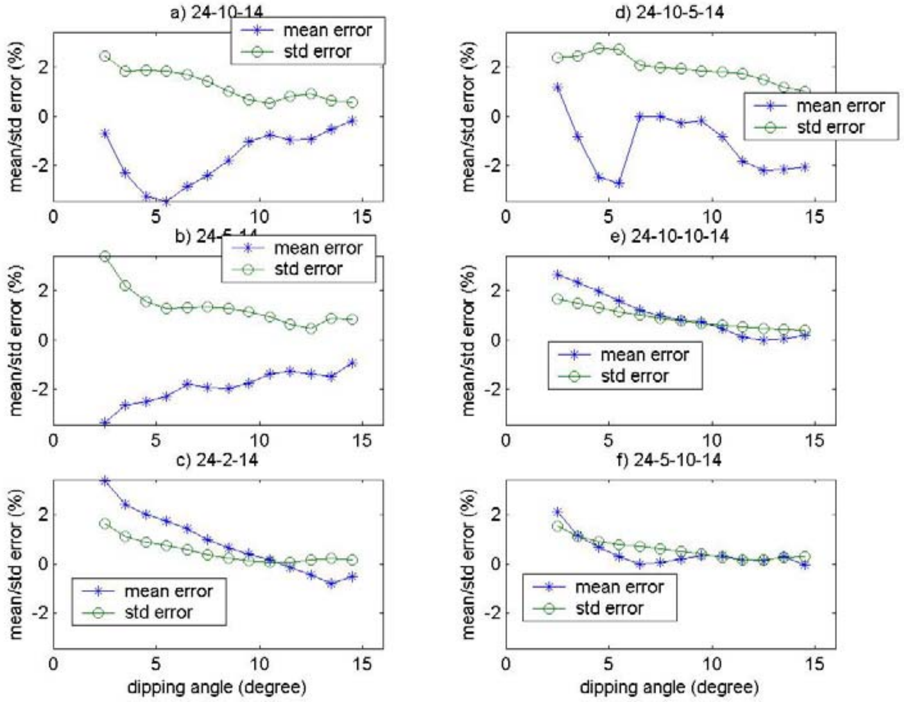


Figure 3.5 Mean and standard deviation of error for each dipping angle of t_{minus}-t_{plus} inputs

The estimated velocities of Testing data 1, where depth to interface at S_1 was fixed at 10 m, were shown in Table 3.3. The estimated top layer velocity, V_1, of testing data sets normalized with its own normalization parameters, agreed quite well with target velocity (Fig.A4). Its mean error was in the range of -12.2 % to -2.8 %. Its standard deviation of error was less than 10 %, or V_1 was estimated with a very good precision. The negative mean error was observed in the estimated top layer velocity for all architecture networks. This means that velocity predicted by a network was less than a target velocity.

The estimated top layer velocity, V_1, of testing data sets normalized with training parameters, agreed very well with target velocity. Its mean error was less 5 % and its standard deviation error was less than 10 %, Fig.A6. The mean and standard deviation of error ranged from -1.6 % to 2.3 % and from 1.4 % to 8.4 % respectively. The error of V_1 estimated by 24-10-5-14 network was larger than the others. Its mean error and standard deviation of error were around -1.3 % and 8.4 % respectively.

For the estimated bottom layer velocity, V_2, of testing data sets normalized with its own normalization parameters, its mean error was less than 10 % except that of 24-2-14 and 24-5-10-14 networks, Fig.A5. Its standard deviation of errors was less than 20 % except that of 24-2-14 and 24-10-14 network. The mean and standard deviation errors estimated by 24-2-14 network were 25.7% and 50.0 % respectively, Fig.A5 c ii). This large error was partly resulted from the setting goal of training process could not be reached by this network. The positive mean error was observed for estimated bottom layer velocity by all architecture networks. This means that the estimated velocity was larger than the target velocity.

The estimated bottom layer velocity, V_2, of testing data sets normalized with training parameters, agree quite well with the target velocity, Fig.A7. Its mean error was less than 5 % except that estimated by 24-10-14 and 24-2-14 networks. Its standard deviation of error was less than 20 % except that estimated by 24-2-14 networks. The mean error and standard deviation of error estimated by 24-2-14 network were 13.7% and 45.2 %, Fig.A7 c ii), which were similar to the estimated V_2 when the normalizing parameters were of the testing data sets.

Table 3.3 Mean error and standard deviation of error of estimated velocities of Testing data 1 with non-separated networks of t_{minus}-t_{plus} inputs

Network	Normalized with testing data				Normalized with training data			
	V1		V2		V1		V2	
	mean error (%)	std error (%)	mean error (%)	std error (%)	mean error (%)	std error (%)	mean error (%)	std error (%)
24-10-14	-3.4	3.5	7.8	21.9	0.5	2.2	7.7	17.7
24-5-14	-12.2	5.9	6.0	14.1	0.0	3.2	1.3	14.5
24-2-14	-4.4	8.2	25.7	50.0	-1.6	5.6	13.7	45.2
24-10-5-14	-11.8	4.9	4.6	18.5	-1.3	8.4	-1.8	8.4
24-10-10-14	-2.8	4.3	6.8	13.1	2.3	1.4	-2.8	5.0
24-5-10-14	-6.7	5.3	10.7	9.7	-0.9	2.6	2.3	4.8

The estimated velocities of testing data sets normalized with training parameters were better than that of testing data normalized by their own parameters. Their mean error and standard deviation of errors were smaller because the normalized parameters of training data set would adjust the testing data sets to be in the system of training data sets.

Table 3.4 Mean error and standard deviation of error of estimated velocities of Testing data 2 with non-separated networks of t_{minus}-t_{plus} inputs

Network	Normalized with testing data				Normalized with training data			
	V1		V2		V1		V2	
	mean error (%)	std error (%)	mean error (%)	std error (%)	mean error (%)	std error (%)	mean error (%)	std error (%)
24-10-14	-3.4	3.5	7.8	21.9	-31.9	3.7	-60.7	92.0
24-5-14	-12.2	5.9	6.0	14.1	-26.2	12.7	-20.0	14.4
24-2-14	-4.4	8.2	25.7	50.0	-40.0	10.2	11.2	44.8
24-10-5-14	-11.8	4.9	4.6	18.5	-17.3	20.9	-25.3	23.6
24-10-10-14	-2.8	4.3	6.8	13.1	-28.9	9.7	-26.2	13.5
24-5-10-14	-6.7	5.3	10.7	9.7	-32.7	4.9	-33.3	8.7

There was no difference in estimating velocities of Testing data 2, where depth to interface at S_1 was fixed at 15 m (Fig.A8 to Fig.A9) and that of Testing data 1, Fig.A4 to Fig.A5, when the testing data was normalized by their own parameters. This was probably caused by equal ratio of normalizing parameters to the value of testing data and the normalization data sets of both testing data were in the same system.

The predicted velocities of Testing data 2, which used training data sets as the normalizing parameters were shown in Fig.A10 and Fig.A11. The mean error and standard deviation of error of top layer velocity, V_1, ranged from -40.0 % to -17.3 % and from 3.7 % to 20.9 % respectively, Table 3.4. The mean and standard deviation error of bottom layer velocity, V_2, were in the range of -60.7 % to 11.2 % and 8.7 % to 92.0 % respectively, Table 3.4. The large error was probably resulted from the training normalizing parameter could not adjust the testing data to be in the same system of training data sets. The trained networks could not predict velocity with a good accuracy for the data set that they were not trained for.

3.2.1.2 travel time inputs

The estimated depth for travel time inputs data sets agree very well with the target depth for every testing data set of 2.5, 8.5, and 14.5 degree dipping angle. Its mean error and standard deviation of error ranged from -3.2 % to 8.0 % and ranged from 1.8 % to 7.0 % respectively (Fig.A12 to Fig.A14). Its mean error was less than 5 % except for the estimated mean error of 36-5-14 network, which was around

8.0 %. Its standard deviation of error was less than 10 %, Table 3.5. Almost errors of predicted depths by any two-layer architecture network had the same sign and their absolute values increased when the geophone was farther away from the first shot point (S_1). This was probably because the training data on the left half of the spread were much more than that on the right half of the spread.

Table 3.5 Mean error and standard deviation of error of estimated depth with non-separated networks of travel time inputs

Network	2.5 degree		8.5 degree		14.5 degree	
	mean error (%)	std error (%)	mean error (%)	std error (%)	mean error (%)	std error (%)
36-10-14	-3.2	4.2	-1.0	2.3	-1.1	1.2
36-5-14	8.0	4.1	-2.4	1.7	1.2	1.1
36-2-14	3.8	1.8	-0.8	0.3	0.9	0.3
36-10-5-14	1.4	6.9	-3.0	3.8	-0.5	1.6
36-10-10-14	4.2	4.6	1.4	0.8	1.0	1.0
36-5-10-14	4.4	2.5	3.4	1.3	2.5	1.1

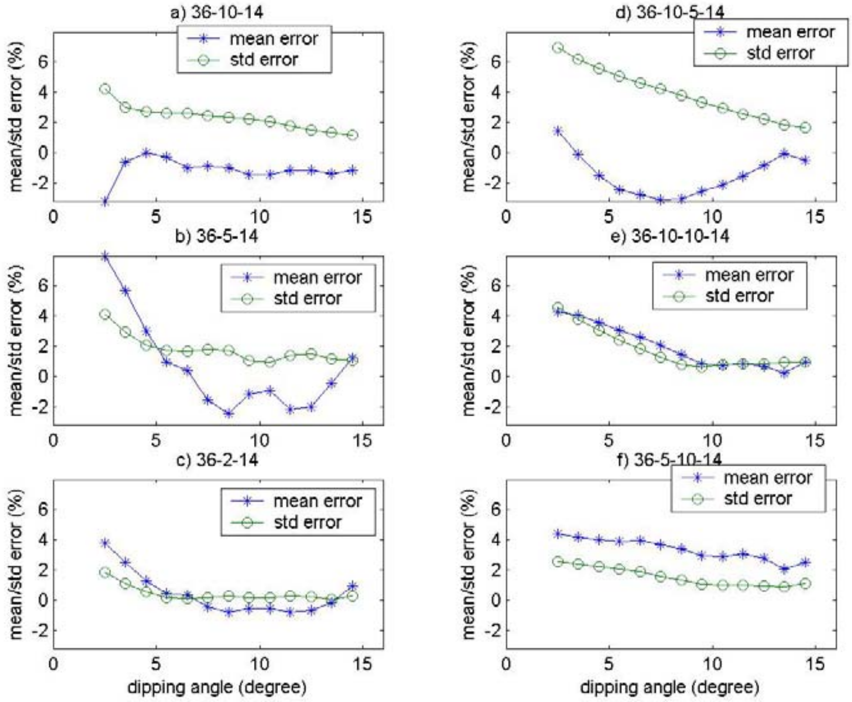


Figure 3.6 Mean and standard deviation of error for each dipping angle of travel time inputs

The error of predicting depth was less than 5 % for all cases of architecture network. The standard deviation of errors decreased when the dipping angle increased but the mean error varied randomly with the dipping angle (Fig.3.6).

The estimated velocities of Testing data 1, where depth to interface at S_1 was fixed at 10 m, were shown in Table 3.6. The estimated top layer velocity, V_1, of testing data sets normalized with their own normalization parameters, agreed quite well with the target velocity (Fig.A15). Its mean error ranged from -7.0 % to -0.3 %. Its standard deviation of error was less than 10 % except for the standard deviation of error estimated by 36-5-4 network, Fig.A15b ii), which was a very good precision in estimating V_1 (Table 3.6). The negative mean error was observed in estimated top layer velocity for all architecture networks. This means that the predicted velocity with a network was less than the target velocity.

The estimated top layer velocity, V_1, of testing data sets normalized with training parameters, agreed very well with the target velocity. Its mean error was less 5 % and its standard deviation of error was less than 10 %, Fig.A17. The mean and standard deviation error were in the range of -5.8 % to 2.3 % and 1.7 % to 9.5 % respectively (Table 3.6). The estimated V_1 error with 36-5-14 network was larger than the other estimated V_1. Its mean error and standard deviation of were around -5.8 % and 9.5 % respectively.

The estimated bottom layer velocity, V_2, of testing data sets normalized with its own normalization parameters, agreed quite well with the target velocity (Fig.A16). Its mean errors and its standard deviation of errors were less than 10 % except that of 36-10-14 and 36-2-14 networks, Fig.A16 a ii) and c ii). The mean error and standard deviation of error estimated by 36-2-14 network were 24.3% and 48.9 %, Fig.A16 c ii). This large error was partly resulted from not enough network parameters in the hidden layer. The positive mean error was observed for estimated bottom layer velocity by most architecture networks (Table 3.6). This means that the estimated velocity was larger than the target velocity.

The estimated bottom layer velocity, V_2, of testing data sets normalized with training parameters, agreed quite well with the target velocity, Table 3.6. Its mean error estimated with two-layer architecture network was larger than 5 % but less than 20 %, Fig.A18 a), b), and c). Its mean error estimated with three-layer architecture network was less than 5 %, Fig.A18 d), e), and f). Its standard deviation of error was less than 20 % except that for estimated by 36-2-14 network. The mean error and standard deviation of error estimated by 36-2-14 network were 12.9% and 44.0 %, Fig.A18 c ii), which were similar to the estimated V_2 when the normalizing parameters were the testing data sets.

Table 3.6 Mean error and standard deviation of error of estimated velocities of Testing data 1 with non-separated networks of travel time inputs

Network	Normalized with testing data				Normalized with training data			
	V1		V2		V1		V2	
	mean error (%)	std error (%)	mean error (%)	std error (%)	mean error (%)	std error (%)	mean error (%)	std error (%)
36-10-14	-4.7	5.2	12.7	26.2	2.2	3.5	7.3	15.1
36-5-14	-6.3	21.5	6.9	9.8	-5.8	9.5	15.0	11.2
36-2-14	-5.9	6.8	24.3	48.9	-0.9	4.2	12.9	44.0
36-10-5-14	-5.9	4.6	3.7	14.8	0.3	5.3	-0.1	12.9
36-10-10-14	-7.0	5.4	-0.8	9.6	1.4	1.7	-3.8	6.1
36-5-10-14	-0.3	3.4	-4.9	11.2	2.3	4.1	-1.0	9.0

The estimated velocities of testing data sets normalized with training parameters were better than the normalized testing data with their own parameters. Their mean and standard deviation errors were smaller because the normalized parameters of training data set would adjust the testing data sets to be in the system of training data sets.

Table 3.7 Mean error and standard deviation of error of estimated velocities of Testing data 2 with non-separated networks of travel time inputs

Network	Normalized with testing data				Normalized with training data			
	V1		V2		V1		V2	
	mean error (%)	std error (%)	mean error (%)	std error (%)	mean error (%)	std error (%)	mean error (%)	std error (%)
36-10-14	-4.7	5.2	12.7	26.2	29.7	19.0	-44.7	150.4
36-5-14	-6.3	21.5	6.9	9.8	79.3	24.1	127.8	40.9
36-2-14	-5.9	6.8	24.3	48.9	-26.3	9.8	4.3	39.5
36-10-5-14	-5.9	4.6	3.7	14.8	-25.9	12.1	-19.4	31.4
36-10-10-14	-7.0	5.4	-0.8	9.6	14.2	12.5	-7.9	28.1
36-5-10-14	-0.3	3.4	-4.9	11.2	-33.9	5.8	-31.7	25.9

There was no difference in estimated velocities of Testing data 2 (Fig.A19 and Fig.A20) and that of Testing data 1 (Fig.A15 and Fig.A16) when the testing data was normalized by their own parameters. This probably caused by the equal ratio of normalizing parameters to the value of testing data and the normalization data sets of both testing data sets were in the same system.

The predicted velocities of Testing data 2, where depth to interface at S_1 was fixed at 15 m, which used training data sets as the normalizing parameters were shown in Table 3.7. The mean and standard deviation error of top layer velocity, V_1, were in the range of -33.9 % to -79.3 % and 5.8 % to 24.1 % respectively, Fig.A21. The mean error and standard deviation of error of bottom layer velocity, V_2, were in the range of -44.7 % to 127.8 % and 25.9 % to 150.4 % respectively, Fig.A22. The large error was probably resulted from the training normalizing parameter could not adjust the testing data to be in the same system of training data sets. The trained networks could not predict velocity with a good accuracy for the data set that they were not trained for.

3.2.2 Separated network

3.2.2.1 Depth network

3.2.2.1.1 t_{minus}-t_{plus} inputs

The trained networks were tested with three testing data sets of different dipping angle; 2.5, 8.5, and 14.5 degree. The depths to interface of receivers predicted by the networks were shown in Fig.A23 to Fig.A25. The estimated depth for t_{minus}-t_{plus} inputs data sets agreed quite well with the target depth for every trained network. Its mean error and standard deviation of error ranged from -2.6 % to 9.7 % and ranged from 0.7 % to 7.0 % respectively, Table 3.8. Its mean error was less than 5 % except that of 24-5-12 and 24-2-12 network, Fig.A23 b ii) and Fig.A24 c ii), which were around 9.2 % and 9.7 % respectively. Its standard deviation of error was less than 10 %, Fig.A23 to Fig.A25. The absolute values increased when the geophone was farther away for the first shot point (S_1) as the estimated depths of non-separated network.

Table 3.8 Mean error and standard deviation of error of estimated depth with depth networks of t_{minus}-t_{plus} inputs

Network	2.5 degree		8.5 degree		14.5 degree	
	mean error (%)	std error (%)	mean error (%)	std error (%)	mean error (%)	std error (%)
24-10-12	2.9	4.9	1.3	2.1	-0.1	1.0
24-5-12	9.2	7.0	1.0	2.9	-0.6	0.7
24-2-12	-4.3	2.1	3.9	1.4	9.7	2.9
24-10-5-12	2.2	4.7	-0.9	2.1	0.2	1.7
24-10-10-12	1.0	0.9	-2.6	1.1	-1.4	1.7
24-5-10-12	-2.3	2.1	-1.0	1.4	0.2	0.5

The mean error and standard deviation of error, Fig.3.7, showed that the error of predicting depth was in the range of -5 % to 5 % for all architecture networks. All standard deviations of error decreased when the dipping angle increased except that of the 24-2-12 and 24-10-10-12 network, Fig.3.7 c) and e). The standard deviation of errors of 24-2-12 and 24-10-10-12 network varied in the range of 0.0 % to 3.0 %. The mean error varied randomly with the dipping angle of interface.

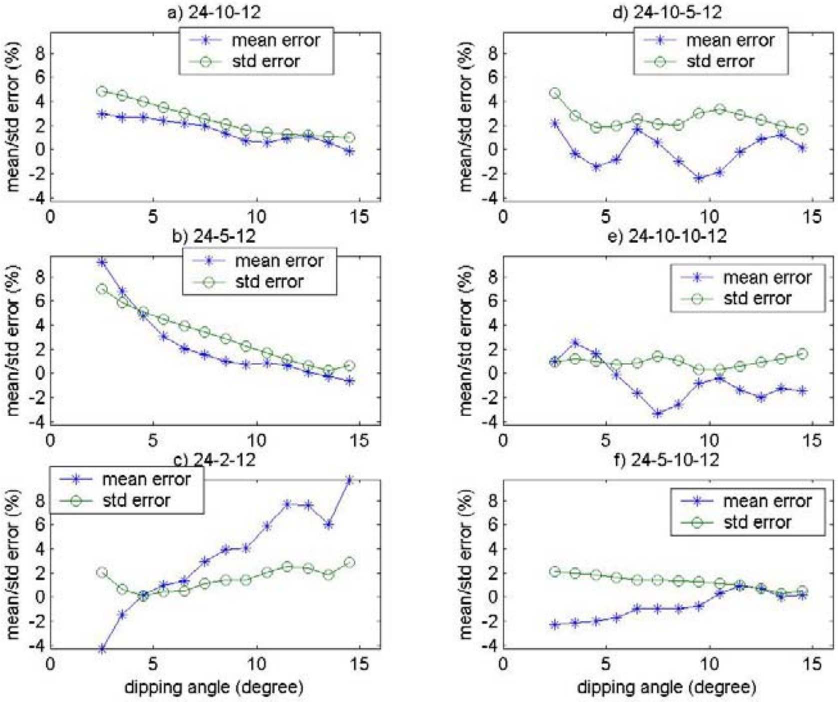


Figure 3.7 Mean and standard deviation of the trained depth network predicting error for each dipping angle of t_{minus}-t_{plus} inputs

3.2.2.1.2 travel time inputs

The estimated depth for travel time inputs data sets agreed quite well with the target depth for all testing data sets of 2.5, 8.5, and 14.5 degree of dipping angle. Its mean error and standard deviation of error ranged from -12.4 % to 2.3 % and ranged from 0.7 % to 7.6 % respectively (Table 3.9). The negative mean errors were observed that most of them were less than 5 % (Table 3.9). This means that depth predicted by a network was shallower than target depth. The standard deviation of error was less than 10 %, Fig.A26 to Fig.A28. The estimated depths error increased when the geophone farther away for the first shot point (S_1) as the estimated depths of non-separated network. The mean errors of estimated depth with travel time depth network were averagely larger than those predicted depth with t_{minus}-t_{plus} inputs network around 2 % to 3 %, which was not significantly difference.

Table 3.9 Mean error and standard deviation of error of estimated depth with depth networks of travel time inputs

Network	2.5 degree		8.5 degree		14.5 degree	
	mean error (%)	std error (%)	mean error (%)	std error (%)	mean error (%)	std error (%)
36-10-12	-12.4	7.6	-2.5	1.2	0.8	1.1
36-5-12	-3.6	6.7	-3.3	3.4	-3.8	3.3
36-2-12	-3.5	1.6	-4.7	1.7	2.6	0.7
36-10-5-12	-1.9	1.0	-3.1	1.2	-5.9	1.7
36-10-10-12	-6.4	7.0	2.3	3.4	-0.2	4.0
36-5-10-12	-10.7	5.4	-1.7	1.0	-1.3	0.8

The mean error and standard deviation of error of predicted depth ranged from -10 % to 5 % for all architecture networks, Fig.3.8. All standard deviations of error decreased when the dipping angle increased except for that of the 36-2-12 and 36-10-5-12 network, Fig.3.8 c) and d). The standard deviation of errors of 36-2-12 and 36-10-5-12 networks varied in the range of 0.0 % to 4.0 %. Most mean errors were in the negative range that means the estimated depth of these trained depth networks was shallower than the target depth.

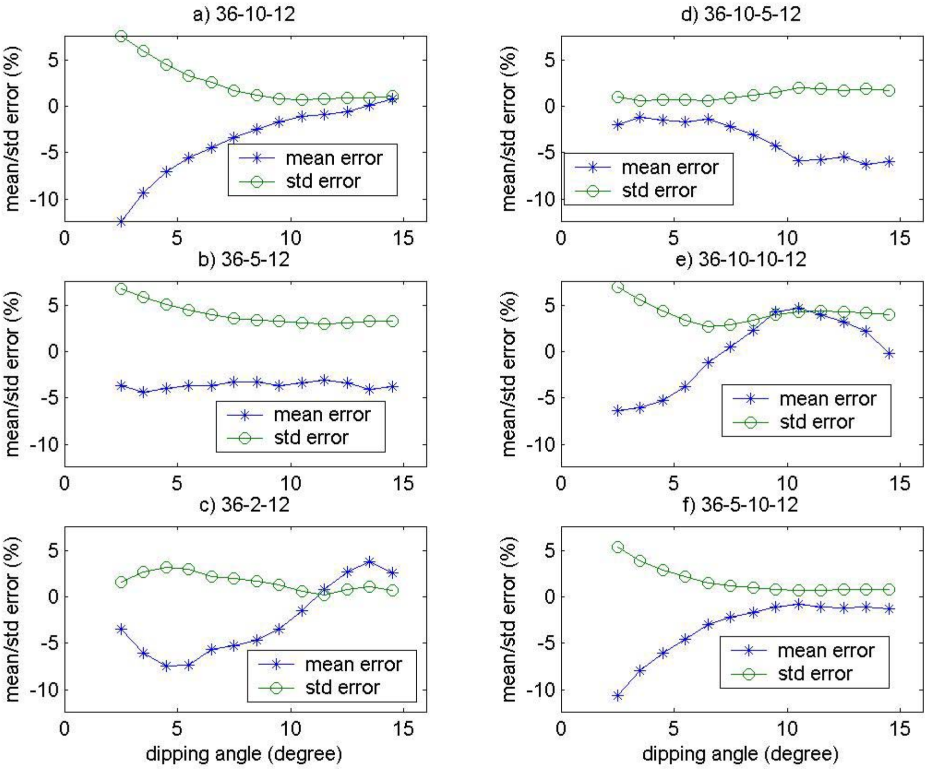


Figure 3.8 Mean and standard deviation of the trained depth network predicting error for each dipping angle of travel time inputs

3.2.2.2 Velocity network

3.2.2.2.1 t_{minus}-t_{plus} inputs

The estimated velocities of Testing data 1, where depth to interface at S_1 was fixed at 10 m, were shown in Table 3.10. The estimated top layer velocity, V_1, of testing data sets normalized by normalization parameters of its own data sets, agreed quite well with the target velocity (Fig.A29). Its mean error ranged from -8.9 % to 11.5 %. Its standard deviation of error was less than 12 %, which was a very good precision. The negative mean error was observed for estimated top layer velocity by all two-layer architecture networks, Fig.A29 a), b), and c). This means that the predicted velocity with two-layer architecture networks was less than the target velocity. The positive mean error was observed for estimated top layer velocity with all three-layer architecture networks, Fig.A29 d), e), and f). This means that the predicted velocity was larger than the target velocity.

The estimated top layer velocity, V_1, of testing data sets normalized by training parameters, agreed very well with the target velocity (Table 3.10). Its mean error was less 5 %, Fig.A31, and its standard deviation of error was less than 10 %, Fig.A31, except for that of 24-10-5-2 network, Fig.A31 d). The mean error and standard deviation of error were in the range of -2.2 % to 8.2 % and 1.0 % to 19.7 % respectively.

The estimated bottom layer velocity, V_2, of testing data sets normalized by normalization parameters of its own data sets, agreed quite well with the target velocity (Fig.A30). Its mean error was less than 15 %, which was in the range of 4.2 % to 14.2 %. Its standard deviation of error was less than 15 %, which was in the range of 5.1 % to 12.1 % (Table 3.10).

The estimated bottom layer velocity, V_2, of testing data sets normalized by training data normalization parameters, agree quite well with target velocity, Fig.A32. Its mean error was less than 5 % except for that of 24-10-5-2 networks. It standard deviation of error was less than 10 %. The estimated V_2 by 24-10-5-2 network were larger than the other estimated V_2. Its mean error and standard deviation of error were 6.2 % and 9.8 % respectively, Fig.A32 d ii).

Table 3.10 Mean error and standard deviation of error of estimated velocities of Testing data 1 with non-separated networks of t_{minus}-t_{plus} inputs

Network	Normalized with testing data				Normalized with training data			
	V1		V2		V1		V2	
	mean error (%)	std error (%)	mean error (%)	std error (%)	mean error (%)	std error (%)	mean error (%)	std error (%)
24-10-2	-8.9	3.8	11.7	12.1	-2.2	2.1	-1.5	7.5
24-5-2	-6.0	2.8	14.2	11.2	0.3	3.6	1.9	5.6
24-2-2	-7.0	3.2	4.2	8.3	0.7	3.8	-0.2	5.9
24-10-5-2	11.5	11.7	13.7	10.3	8.2	19.7	6.2	9.8
24-10-10-2	5.9	3.8	10.5	8.9	0.8	1.0	2.4	1.8
24-5-10-2	5.4	2.6	6.8	5.1	2.8	1.7	3.1	4.3

The estimated velocities of testing data sets normalized by normalization parameters of training data sets were better than that of testing data set normalized by its own data sets. Its mean error and standard deviation of error were smaller because the training data normalizing parameters adjusted the testing data sets to be in the system of training data sets.

There was no difference in estimated velocities of Testing data 2 (Fig.A33 and Fig.A34) and that of Testing data 1 (Fig.A29 and Fig.A30) when the testing data was normalized by its own parameters as the results of non-separated network (Table 3.11).

Table 3.11 Mean error and standard deviation of error of estimated velocities of Testing data 2 with non-separated networks of t_{minus}-t_{plus} inputs

Network	Normalized with testing data				Normalized with training data			
	V1		V2		V1		V2	
	mean error (%)	std error (%)	mean error (%)	std error (%)	mean error (%)	std error (%)	mean error (%)	std error (%)
24-10-2	-8.9	3.8	11.7	12.1	-36.0	8.3	-43.3	22.7
24-5-2	-6.0	2.8	14.2	11.2	-24.9	13.3	-31.7	9.6
24-2-2	-7.0	3.2	4.2	8.3	-25.2	13.2	-28.8	7.8
24-10-5-2	11.5	11.7	13.7	10.3	46.0	25.8	38.0	15.2
24-10-10-2	5.9	3.8	10.5	8.9	34.1	9.9	28.3	10.0
24-5-10-2	5.4	2.6	6.8	5.1	27.5	8.5	28.5	9.6

The predicted velocities of Testing data 2, where depth to interface at S_1 was fixed at 15 m, normalized by normalization parameters of training data sets were shown in Fig.A35 and Fig.A36. The mean error and standard deviation of error of top layer velocity, V_1, were in the range of -36.0 % to 46.0 % and 8.3 % to 25.8 % respectively, Fig.A35. The mean error and standard deviation of error of bottom layer velocity, V_2, were in the range of -43.3 % to 38.0 % and 7.8 % to 22.7 % respectively, Fig.A36.

3.2.2.2.2 travel time inputs

The estimated velocities of Testing data 1, where depth to interface at S_1 was fixed at 10 m, were shown in Fig.A37 to Fig.A40. The estimated top layer velocity, V_1, of testing data sets normalized by its own normalization parameters, agreed quite well with the target velocity (Table 3.12). Its mean error was in the range of -6.2 % to 7.0 %. Its standard deviation of error was less than 10 %, which was a very good precision. The negative mean error was observed for estimated top layer velocity by all two-layer architecture networks, Fig.A37 a), b), and c). This means that the predicted velocity was less than the target velocity. The positive mean error was observed for estimated top layer velocity with all three-layer architecture networks, Fig.A37 d), e), and f). This means that the predicted velocity was larger than the target velocity.

The estimated top layer velocity, V_1, of testing data sets normalized by training parameters, agreed very well with the target velocity, Table 3.12. Its mean error was less 5 %, and its standard deviation of error was less than 10 %, Fig.A39, except for the predicted V_1 by 36-5-10-2 network, Fig.A39 e). The mean and standard deviation error were in the range of 0.2 % to 7.3 % and 2.0 % to 10.8 % respectively, Table 3.12.

The estimated bottom layer velocity, V_2, of testing data sets normalized by its own normalization parameters, agree quite well with the target velocity (Fig.A38). Its mean errors were less than 12 %, which ranged from -1.7 % to 11.5 %. Its standard deviations of error were less than 21 %, which were in the range of 5.7 % to 20.9 % (Table 3.12). The negative mean error was observed for estimated top layer velocity with all two-layer architecture networks, Fig.A38 a), b), and c). This means that the predicted velocity was less than the target velocity. The positive mean error was observed for estimated top layer velocity with all three-layer architecture networks, Fig.A38 d), e), and f). This means that the predicted velocity was larger than the target velocity.

Table 3.12 Mean error and standard deviation of error of estimated velocities of Testing data 1 with non-separated networks of travel time inputs

Network	Normalized with testing data				Normalized with training data			
	V1		V2		V1		V2	
	mean error (%)	std error (%)	mean error (%)	std error (%)	mean error (%)	std error (%)	mean error (%)	std error (%)
36-10-2	-6.2	7.2	-1.3	14.8	0.2	2.0	2.2	12.4
36-5-2	-2.7	3.0	-1.2	7.3	0.7	3.5	-0.5	5.2
36-2-2	-2.5	3.0	-1.7	7.7	1.0	4.3	0.5	5.4
36-10-5-2	6.6	6.6	11.5	15.5	4.1	5.3	11.4	17.7
36-10-10-2	1.9	2.6	6.8	5.7	3.2	4.0	3.5	3.8
36-5-10-2	7.0	8.4	10.0	20.9	7.3	10.8	7.7	6.5

The estimated bottom layer velocity, V_2, of testing data sets normalized by training parameters, agreed quite well with the target velocity, Fig.A40. Its mean error was less than 5 % except for that of 36-10-5-2 and 36-5-10-2 networks, Table 3.12. Its standard deviation of error was less than 10 %. The estimated V_2 by 36-10-5-2 network were larger than the other estimated V_2 except for that of 36-10-2 and 36-10-5-2 network. Its mean error and standard deviation of error predicted by 36-10-5-2 network were 11.4 % and 17.7 % respectively, Fig.A40 d ii).

The error of estimated velocities of testing normalized by training data normalization parameters better than that of the data set normalized by testing parameters because the train normalization parameters adjusted the testing data sets to be in the system of training data sets.

There was no difference in estimated velocities of Testing data 2 (Fig.A41 and Fig.A42) and that of Testing data 1 (Fig.A37 and Fig.A38) when the testing data was normalized by its own parameters (Table 3.12 and Table 3.13). This was probably caused by equal ratio of normalizing parameters to the value of testing data and the normalization data sets of both testing data were in the same system.

Table 3.13 Mean error and standard deviation of error of estimated velocities of Testing data 2 with non-separated networks of travel time inputs

Network	Normalized with testing data				Normalized with training data			
	V1		V2		V1		V2	
	mean error (%)	std error (%)	mean error (%)	std error (%)	mean error (%)	std error (%)	mean error (%)	std error (%)
36-10-2	-6.2	7.2	-1.3	14.8	16.5	8.8	-52.8	58.4
36-5-2	-2.7	3.0	-1.2	7.3	-27.5	7.4	-33.1	31.1
36-2-2	-2.5	3.0	-1.7	7.7	-22.8	12.8	4.3	15.1
36-10-5-2	6.6	6.6	11.5	15.5	44.3	50.9	25.5	30.1
36-10-10-2	1.9	2.6	6.8	5.7	29.8	10.1	58.4	34.1
36-5-10-2	7.0	8.4	10.0	20.9	23.2	16.6	24.6	23.2

The predicted velocities of Testing data 2, where depth to interface at S_1 was fixed at 15 m, which used training data sets as the normalizing parameters were shown in Fig.A43 and Fig.A44. The mean and standard deviation error of top layer velocity, V_1, ranged from -27.5 % to 44.3 % and from 7.4 % to 50.9 % respectively, Table 3.13. The mean error and standard deviation of error of bottom layer velocity,

V_2, were in the range of -52.8 % to 58.4 % and 15.1 % to 58.4 % respectively, Fig.A44. The large error was probably resulted from the training normalization parameter could not adjust the testing data to be in the same system of training data sets. The trained networks could not predict a good velocity that they did not study.

In summary, any type of input data, either t_{minus}-t_{plus} or travel time input could be used to determine depth to interface with the same accuracy, or with ±10 %. The non-separated network determined the depth to interface better than the depth network about 1 % to 3 %. Generally the three-layer architecture network determined depth to interface better than the two-layer architecture, except in non-separated network with travel time inputs, two-layer architecture determined the depth to interface better than three-layer architecture, shown in Table 3.2, Table 3.5, Table 3.8, and Table 3.9.

The studied network could determine top layer velocity, V_1, with ± 10 % error and bottom layer velocity, V_2, with ± 20 % error, as shown in Table 3.3, Table 3.4, Table 3.6, Table 3.7, Table 3.10, Table 3.11, Table 3.12, and Table 3.13. With either t_{minus}-t_{plus} inputs or travel time inputs, the accuracy of the estimated V_1 was the same for non-separated networks and velocity networks. In non-separated network, three-layer architecture estimated V_2 more accurate than two-layer architecture, but in velocity networks, two-layer architecture estimated V_2 more accurate than three-layer architecture.

In addition, it could be observed that for the Testing data 1 whose depth to interface beneath S_1 was fixed at 10 m, the estimated velocities of testing data normalized with training parameters was more accurate than that of testing data normalized by its own parameters. For the Testing data 2 whose depth to interface beneath S_1 was fixed at 15 m, the estimated velocities of testing data normalized with its own parameters was more accurate than that of testing data normalized by training parameters.

3.3 Network for two-layer irregular interface structure

3.3.1 The results of the depth networks for irregular interface

Error distributions of training data which were applied to all six designed network architectures were shown in Fig.3.9. It could be observed that their mean errors are less than 3.5 % and their standard deviations of error are approximately 10 % except that of the 72-10-10-24 network architecture whose standard deviation is about 15.2 %.

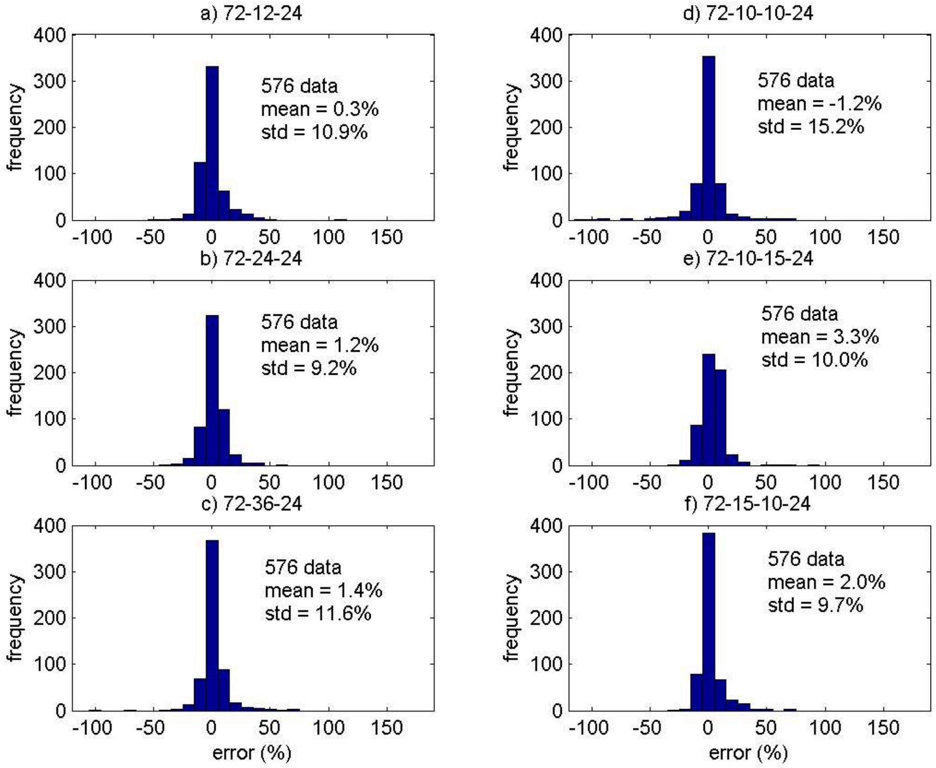


Figure 3.9 Error distributions for all predicted depths of training data sets

Among three-layer architecture networks, even though the predicted depth of the 72-10-10-24 network had the lowest mean error of -1.2 %, but its standard deviation error was greater than 10 %. The 72-10-10-24 network was then considered not a good network for depth determination of the irregular interface case. The suitable network was the 72-15-10-24 network because this network gave the best precision, smallest standard deviation of about 9.7 %, of the predicting depth, even though its accuracy of predicting depths, 2.0 %, is greater than that of the 72-10-10-24 network. Therefore the three-layer architecture, whose first hidden layer has more number of neurons than its second hidden layer is likely to be the good architecture among the three-layer architecture network for predicting depth of irregular interface.

Among two-layer architecture networks, the accuracy of the network was decreased, or its mean error was increased, when the number of neurons in its hidden layer was increased (Fig. 3.9 a), 3.9 b) and 3.9 c)). The standard deviation of error of the 72-24-24 network was smallest, 9.2 %, whereas those of the rests were about 11 %. The standard deviation of errors of all two-layer networks could be considered to be approximately the same, and then the suitable architecture of two-layer network should be 72-12-24 because its mean error was lowest. Two-layer architecture networks were probably better than three-layer architecture networks in estimating depths of irregular interface because their means and standard deviation of errors were less than those of three-layer networks.

Case I : Shallow interface depth

A prepared testing data set of 2-m average interface depth was applied to check the performance of all trained networks. The interface depth of this data set was varying between 1.2 m and 2.5 m, which separated the top and bottom mediums of 588 m/s and 1760 m/s velocities. The predicted depths of each network were shown in Fig.3.10. The predicted depth of all trained networks were inaccurate because of quite a large value of mean and standard deviation of error, i.e. 33.2 % to 84.3 % in mean error and 34.7 % to 49.6 % in standard deviation of error. The predicted depths obtained from all trained networks were about 0.6 m to 1.7 m deeper than the true interface depth since the mean errors of all networks were positive.

Therefore, in shallow interface case of about 2 m depth, among two-layer architecture network, the 72-36-24 network was likely to perform better than others even though its mean error and standard deviation of error were quite large, 38.8 % and 39.4 % respectively. Whereas among three-layer architecture networks, the interface depth determined from the 72-10-10-24 and 72-10-15-24 networks were more accurate than the 72-15-10-24 network. The mean errors of the 72-10-10-24 and 72-10-15-24 networks were 33.4 % and 33.2 % respectively. Since the standard deviation of error of the 72-10-10-24 network, 34.7 %, was smaller than that of the

72-15-10-24 network, 44.7 %, therefore the 72-10-10-24 network was considered to be a good network in determining shallow interface depth. This was contrary with the overall performance of the 72-10-10-24 network, which was not very good with training data sets. The cause of this might be the difference in number of training data sets, which used for calculating the mean and standard deviation.

The accuracy of predicted results for 2-m interface depth was very poor because mean error and standard deviation of error of designed architecture network were very large. Number of training data sets might be responsible for this low accuracy because there were only 4 training data sets of shallow interface in altogether 24 training data sets. Another possibility was due to little information of direct wave in data sets.

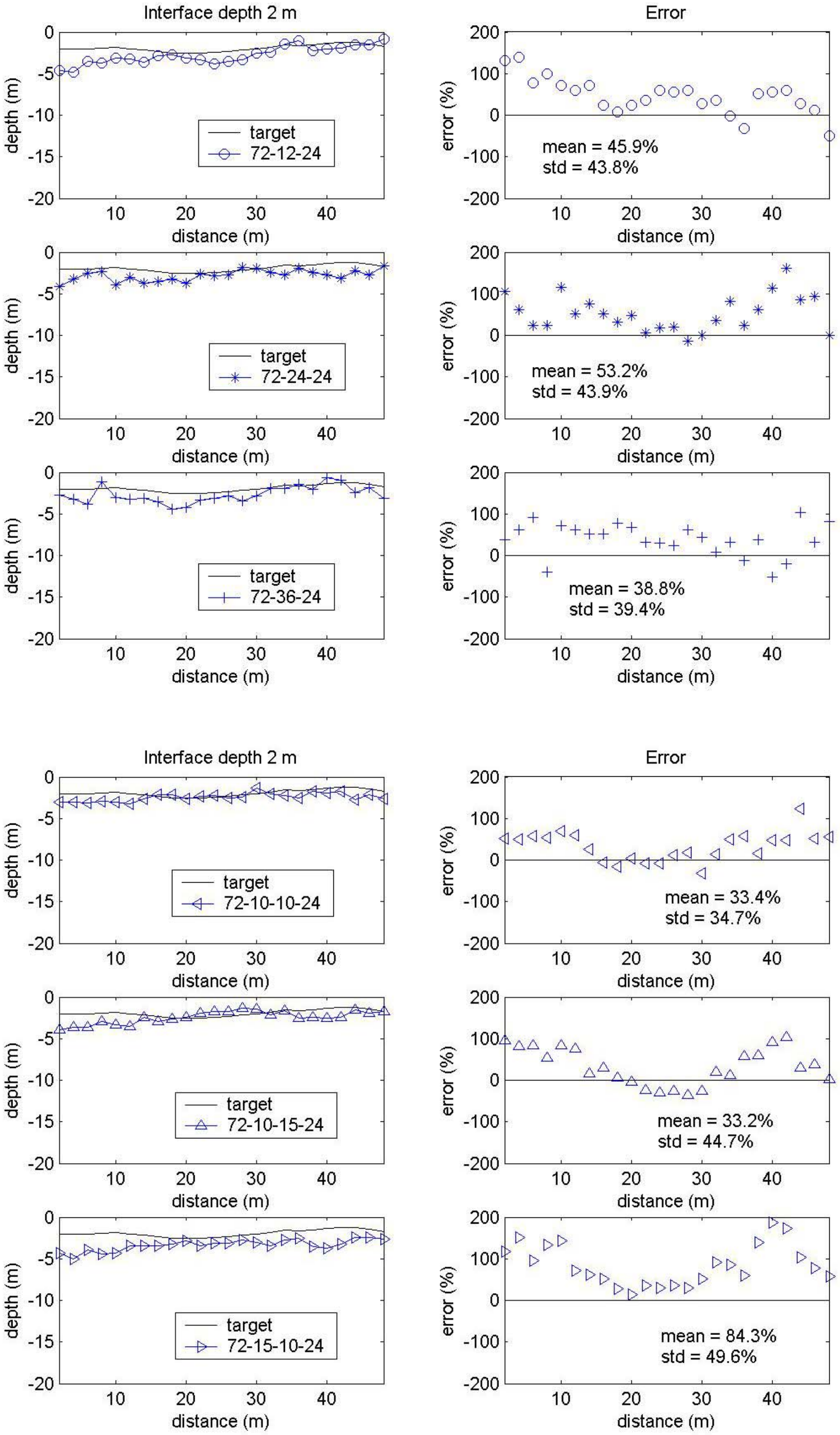


Figure 3.10 Predicted depth of an average 2-m interface depth testing data set

Case II: Medium interface depth.

The second testing data set of 6-m average interface depth was applied to all designed architecture networks to test their performance. The interface depth of this data set varies between 5.6 m and 6.9 m. The seismic velocities of the top and bottom layers of the ground were 758 m/s and 4305 m/s respectively, Fig.3.11. The accuracy of predicted depth was clearly better than that of the first testing data set of shallow interface. For two-layer architecture networks, the mean errors of the 72-12-24, 72-24-24, and 72-36-24 networks were -6.0 %, -6.2 %, and -7.6 % respectively. It could be observed that the mean error increased when the number of neurons in the hidden layer of the two-layer architecture network increased. The negative mean errors of -7.6 % to -6.0 % would cause the predicted interface depth about 0.4 m to 0.5 m shallower than the true depth. The standard deviation of error of the two-layer networks was approximately 13.0 % to 14.0 %. This caused a deviation in the predicted depth of about ±0.8 m, which was much smaller than the deviation in the predicted depth of the first testing data set. Since the standard deviation of the error in the second testing data set was approximately the same, the 72-12-24 network was then considered to be the best network among the two-layer architecture networks in estimating depth for the medium interface depth case.

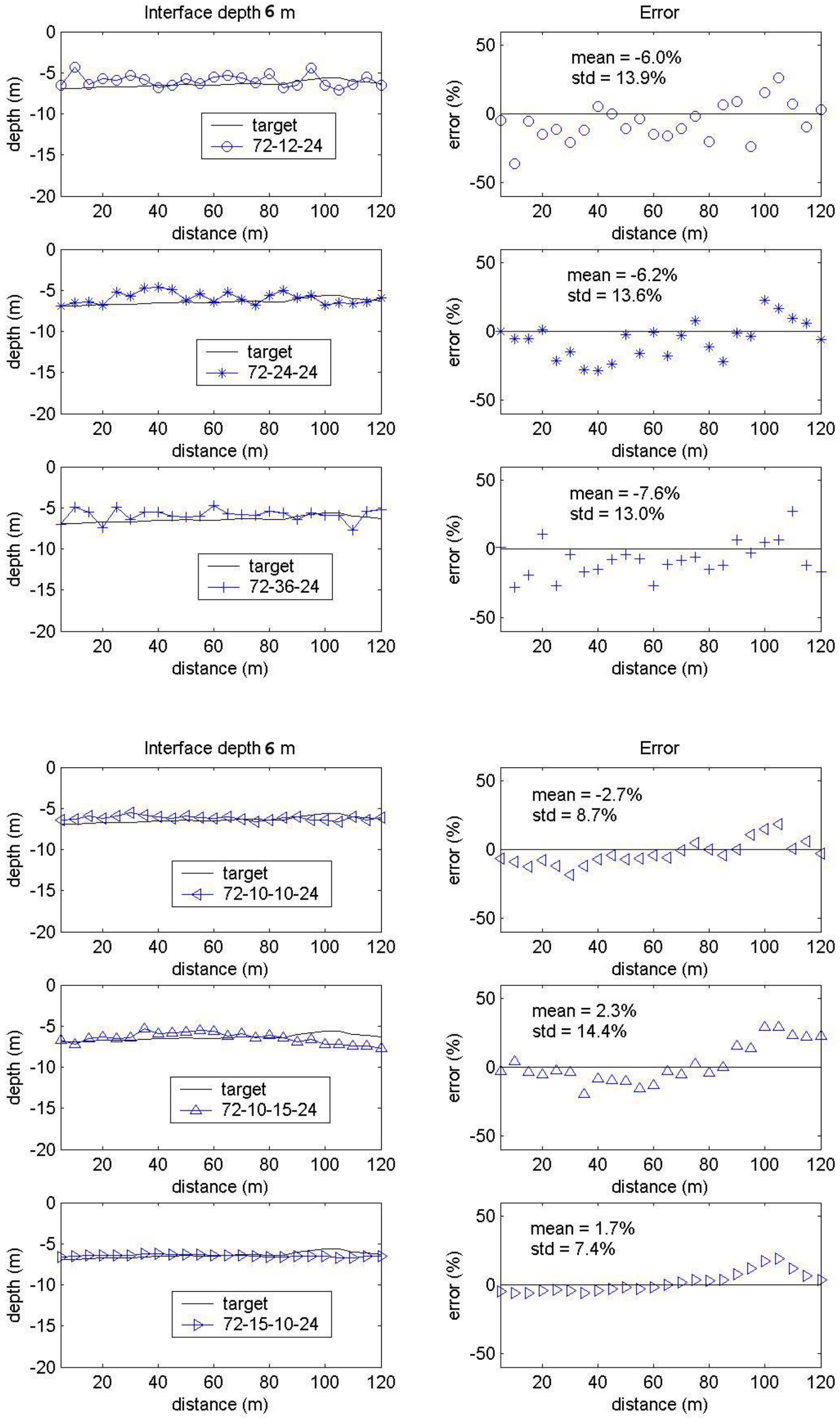


Figure 3.11 Predicted depth of an average 6-m interface depth testing data set

For three layers architecture networks, mean errors of the 72-10-10-24, 72-10-15-24 and 72-15-10-24 networks were –2.7 %, 2.3 % and 1.7 % respectively, whereas their standard deviation of errors were 8.7 %, 14.4 % and 7.4 % respectively. They were significantly smaller than those of the two-layer architecture networks, which resulted in more accurate and better precision of estimating depth. The best network among three-layer architecture networks was the 72-15-10-24 network, whose number of neurons in the first hidden layer was more than that of the second hidden layer. The error of this architecture network in estimating depth for the medium interface depth case was 1.7 % ±7.4 %.

All designed architecture networks could estimate the interface depth of this medium case, average 6-m depth, with more accurate and better precision than that of the shallow case of average 2-m depth. This was probably resulted from the right number of training data sets of the medium case, i.e. 10 data sets, were used in training process of the network.

Case III: Deep interface case.

The depth to interface of the last testing data set varied from 8.8 m to 10.9 m with an average depth of about 10 m. This interface separated the top and bottom layers of ground whose seismic velocities were 468 m/s and 3441 m/s respectively. The mean errors of the estimated depth to interface for the trained networks were all positive, see Fig.3.12, or an estimated depth obtained from a network was greater than the true depth.

For two-layer architecture networks, the mean errors of the 72-12-24, 72-24-24 and 72-36-24 networks were 10.9 %, 0.8 % and 8.8 % respectively, whereas their standard deviation of errors were 10.1 %, 19.7 % and 24.5 % respectively. Even though the mean error of the 72-24-24 network, 0.8 % or about 0.2 m, was the lowest among two-layer network, its standard deviation of error given was quite large, 19.7 % or about ± 2.0 m. It could not be a suitable network among two-layer architecture networks used for estimating depth to interface in the average 10-m deep interface case. The 72-12-24 network with mean error of 10.9 % and standard deviation of error of 10.1 % was likely to perform best among two-layer architecture network.

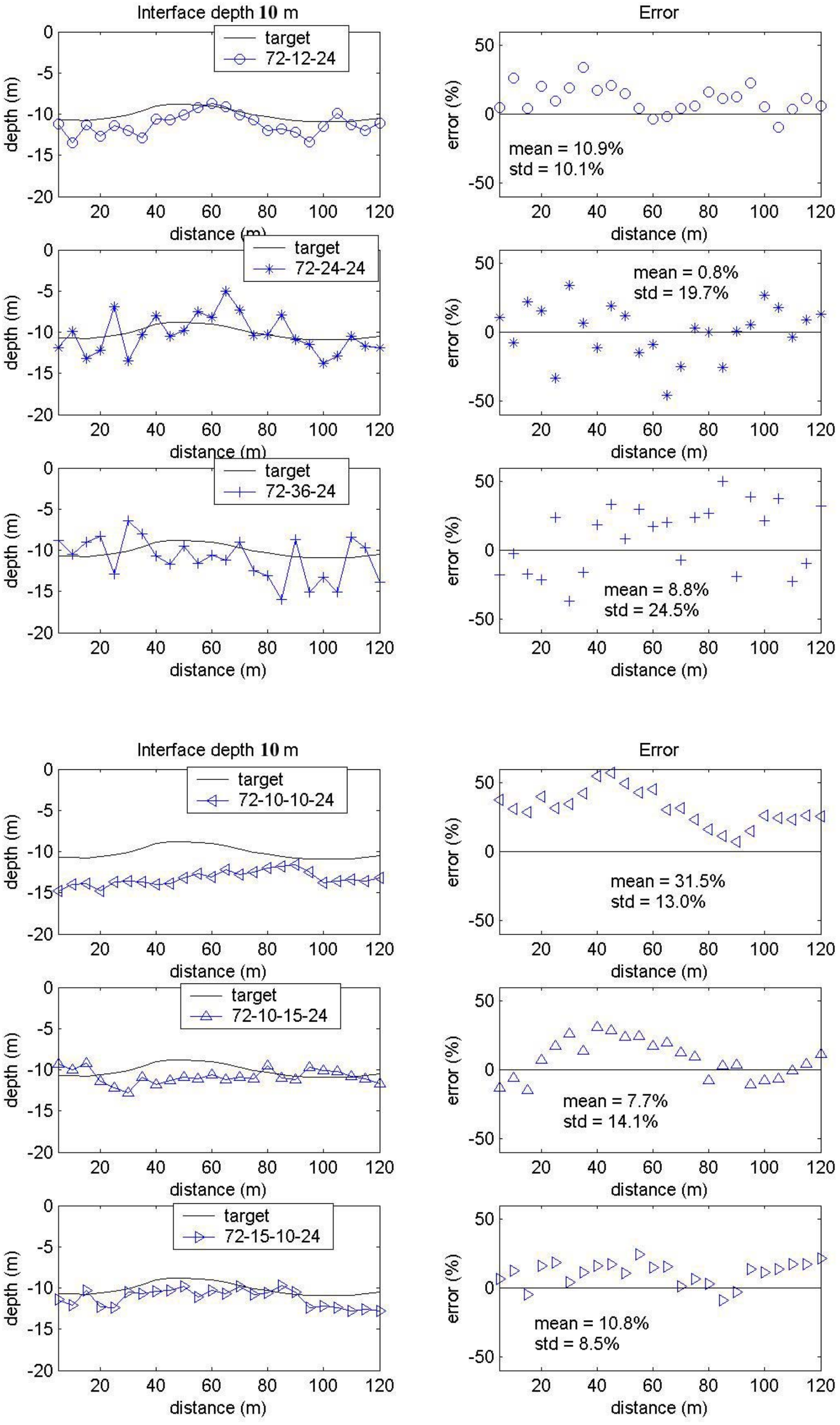


Figure 3.12 Predicted depth of an average 10-m interface depth testing data set

For three-layer architecture networks, the mean errors of the 72-10-10-24, 72-10-15-24 and 72-15-10-24 networks were 31.5 %, 7.7 % and 10.8 % respectively, whereas their standard deviation of error were 13.0 %, 14.1 % and 8.5 % respectively. The depth to interface determined by the 72-10-15-24 network was the most accurate among the three-layer architecture network, i.e. about 7.7 % mean error, where as the 72-15-10-24 network estimated interface depth with the most precision, about 8.5 %. By emphasizing on the standard deviation of error, the 72-15-10-24 network was likely to be the best network among three-layer architecture network in estimating depth to interface.

Evidently, the performance of network depends on a number of data sets used in training the designed networks. The shallow interface of 2-m average depth was the case of not enough training data sets. There were only 4 training data sets for shallow interface whereas there were 10 training data sets each for medium and deep interface. Mean error and standard deviation of error of the estimated depth obtained from shallow interface testing data set, were very much larger than those obtained from the medium and deep interface testing data sets, see Fig.3.10, 3.11 and 3.12.

In order to determine which architecture network worked well for all cases of data sets, errors of predicted depths of the testing data sets were compared among architecture networks, as shown in Fig.3.13. There were altogether 72 predicted errors obtained from these three testing data sets, 24 from each testing data set. The mean error of these testing data sets ranged from 13.3 % to 32.3 % and their standard deviation of error ranged from 27.4 % to 47.0 %. It could be observed that the mean errors and standard deviation of errors of testing data sets were larger than those of training data sets, approximately 10 times and 3 times respectively, see also Fig. 3.10, 3.11 and 3.12. Very much different in mean error and standard deviation of error between training data sets and testing data sets probably resulted from large errors and large standard deviation of error of shallow interface testing data set in addition to the difference of training and testing data sets themselves.

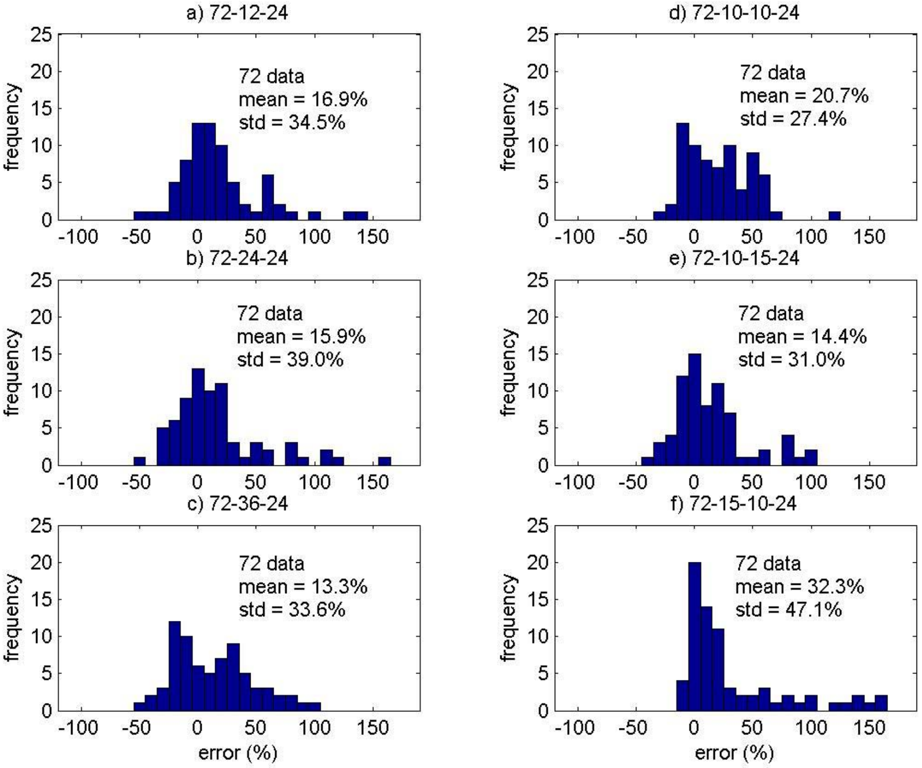


Figure 3.13 Error distributions for all predicted depths of testing data sets

Generally, the mean errors of three-layer networks were greater than those of two-layer networks, except that of the 72-20-15-24 network whose mean error, 14.4 %, was in the same range as those of two-layer network, Fig.3.13. If mean error in depth of less than 20 % was allowed in predicting depth, then the 72-12-24, 72-24-24, 72-36-24 and 72-10-15-24 networks, Fig. 3.14 a), 3.14 b), 3.14 c) and 3.14 f), would be considered as good depth networks for irregular interface. The mean errors of these three networks were 16.9 %, 15.9 %, 13.3 % and 14.4 % respectively, whereas their standard deviation of errors were 34.5 %, 39.0 %, 33.6 % and 31.0 % respectively. The error distributions of these networks seem to have two group of populations, a major one with its mean error around 0 % and a minor one with its mean error around 50 % to 90 %, clearly observed on the 72-12-24, 72-10-15-24 and 72-15-10-24 networks. The minor group of error distribution were probably belong to testing data set of shallow interface, where small number of training data sets of shallow interface was used in training the designed network.

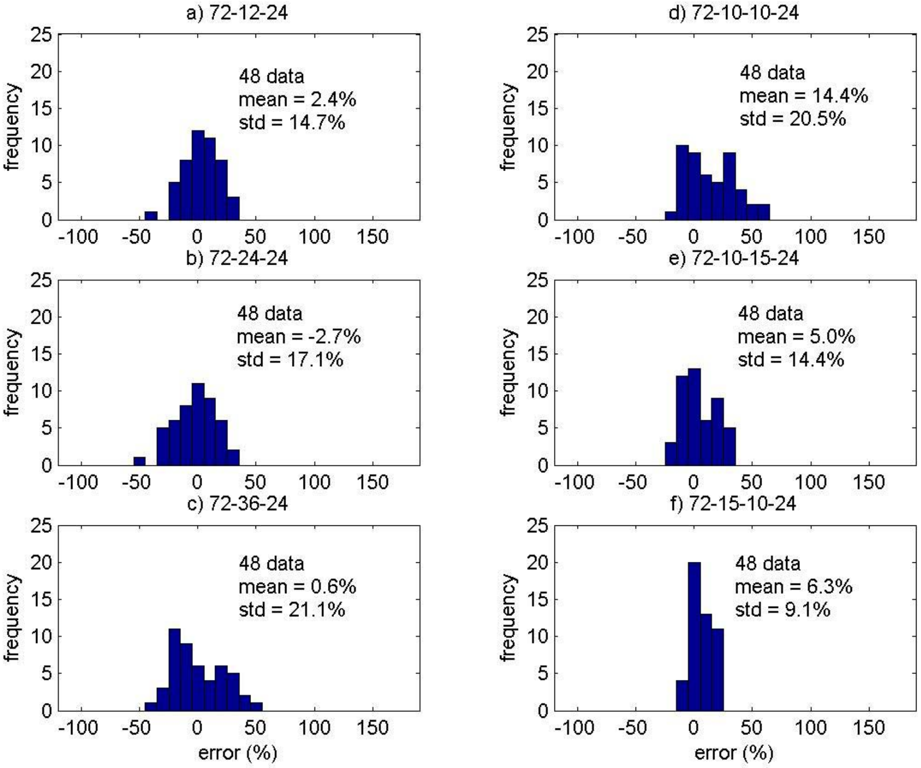


Figure 3.14 Error distributions for predicted depths of intermediate and deep interface testing data sets

Error distributions of all networks, tested with only medium and deep interface data sets, showed satisfactory low mean and standard deviation of error (Fig.3.14). The standard deviation of error of the 72-12-24, 72-24-24 and 72-10-15-24 networks, 14.7 %, 17.1 % and 14.4 % respectively, were the lowest group among the designed and trained networks. Their means of error, 2.4 %, -2.7 % and 5.0 % respectively, were very good and acceptable. The 72-36-24 network had very low mean error of 0.6 % but quite a large standard deviation of error, 21.1 %. Even though mean and standard deviation of error of the 72-15-10-24 networks, 6.3 % and 9.1 % respectively, were the smallest in this testing but in the previous test accompanying with shallow interface data set its mean and standard deviation of error were comparably large. The performance of the 72-12-24 network was probably better than that of the 72-10-15-24 because the mean error of the 72-12-24 network was lower in case where all kinds of testing data sets were employed in the test. Therefore the 72-12-24 network was considered to be the most suitable network for estimating depth of irregular interface.

3.3.2 The velocity networks for irregular interface

The velocity networks were designed to estimate velocities of two-layer earth with irregular interface. Architecture of the designed velocity networks was similar to that of the depth networks, except that there were only 2 neurons in the output layer. These two outputs were velocities of the top and bottom layers of ground. Similar training and testing data sets used in depth networks were employed in training and testing the designed velocity networks. The targets of the training data sets were velocities of the top and bottom ground layers ranging from 229 to 1,752 m/s and 1,185 to 5,644 m/s respectively (Changlow, 2002).

Three testing data sets for velocity network were similar to those of the depth network as followings;

Case I: Shallow interface of about 2-m average depth data set. Its depth ranged from 1.2 m to 2.5 m and its velocities in the top and bottom layers of ground were 588 and 1,760 m/s respectively.

Case II: Medium interface of about 6-m average depth data set. Its depth ranged from 5.6 m to 6.9 m and its velocities in the top and bottom layers of ground were 758 and 4,305 m/s respectively.

Case III: Deep interface of about 10-m average depth data set. Its depth ranged from 8.8 m to 10.9 m and its velocities in the top and bottom layers of ground were 468 and 3,441 m/s respectively.

The top and bottom velocities, V_1 and V_2, estimated from the trained velocity networks and their relative error in percent were plotted against the true velocities of the ground layers for all training and testing data sets (Fig.3.15 and 3.16). In these figures, the estimated velocity and the error were shown on the left column and the right column respectively.

The testing data set with top layer target velocity of 758 m/s yielded the maximum positive error for every network (Fig.3.15 and Fig.3.17). Small number of training data sets within the same target velocity might account for highest error in testing data set. Another possibility might be too little information of direct wave on the travel time-distance data. The travel time-distance curves of this testing data set was then examined and only refracted segment was observed on the backward shooting.

Among two-layer architecture, the 72-12-2 network appeared to be a good network for estimating velocity of top layer. Its mean and standard deviation of error were 13.4 % and 22.4 % respectively. Even though mean error of the 72-24-2 network, -7.8 %, was less than that of the 72-12-2 network but its standard deviation of error, 38.4 %, was very much larger than that of the 72-12-2 network. The 72-10-10-2 network was the best network among three-layer network, even when compared with two-layer network as well, in estimating top layer velocity of ground. Its mean and standard deviation of error were 2 % and 19.4 % respectively.

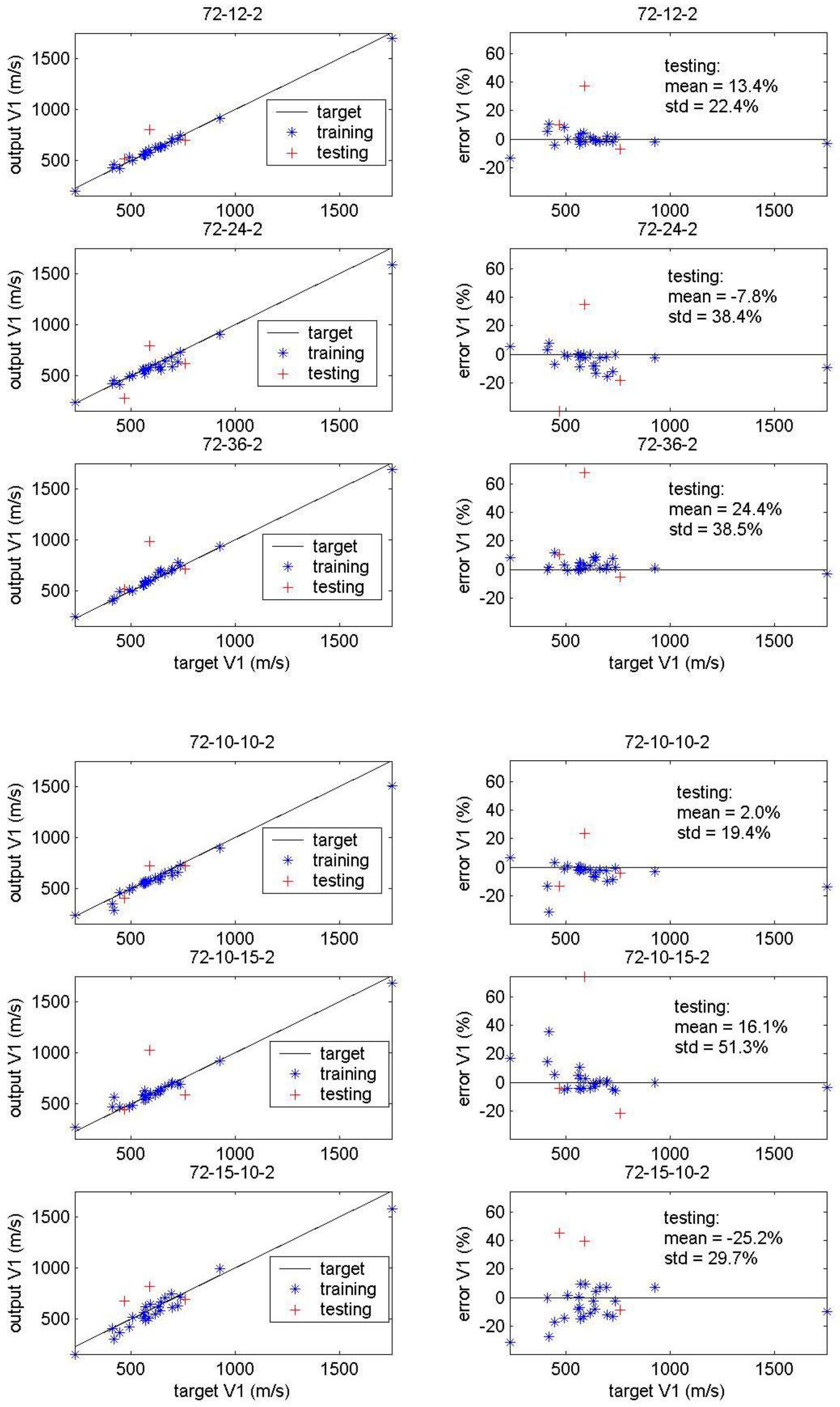


Figure 3.15 Predicted V_1 of training and testing data sets by each velocity network

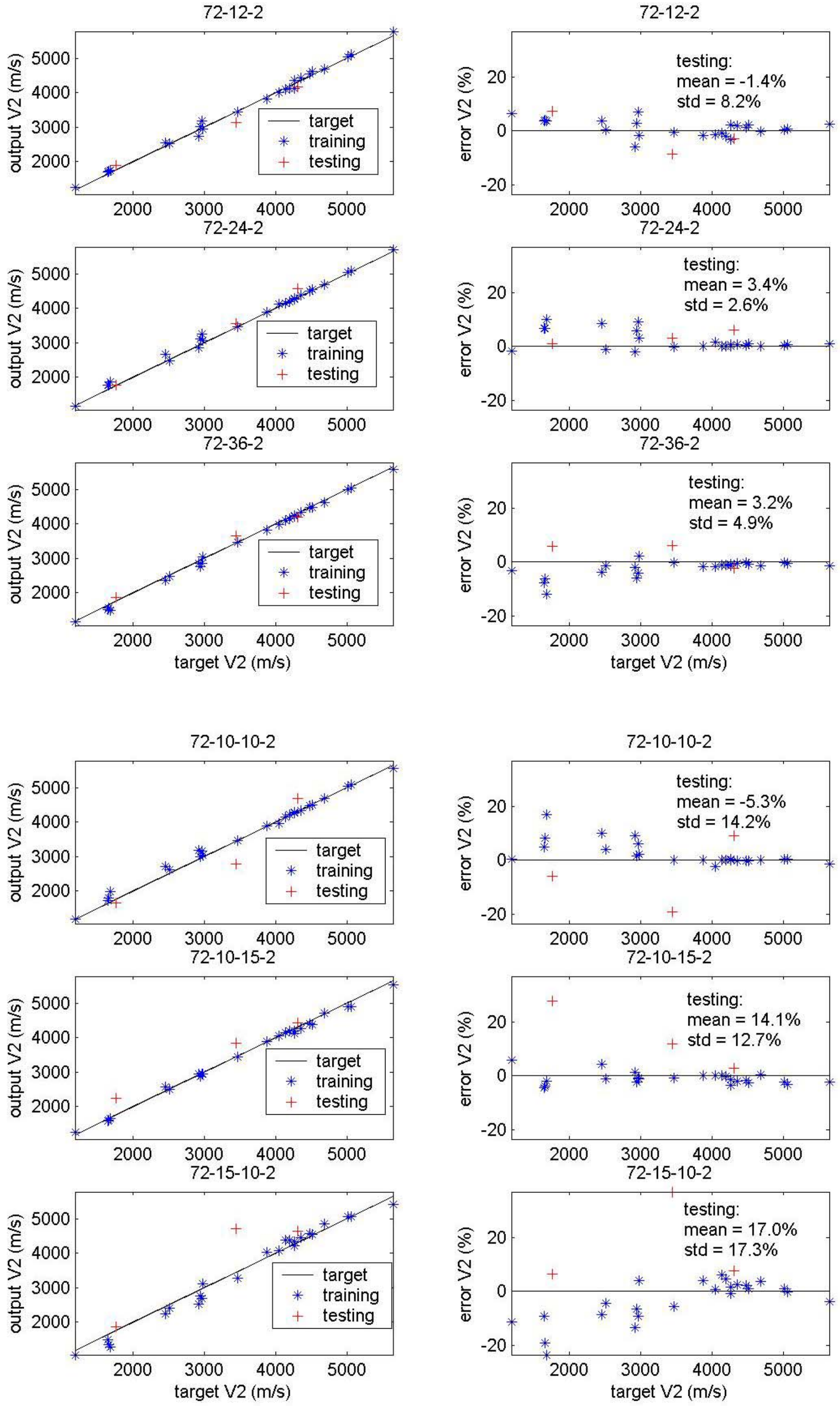
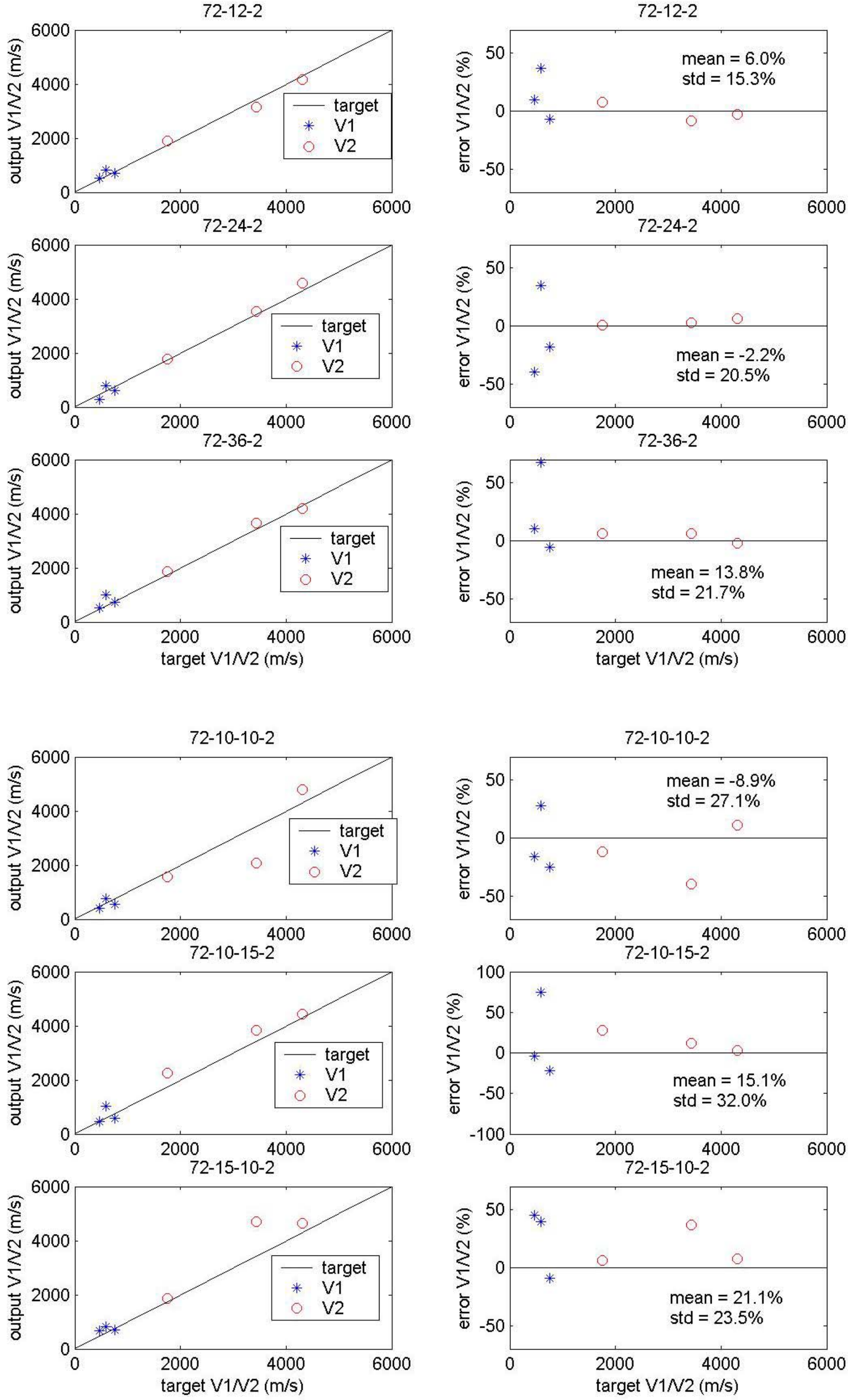


Figure 3.16 Predicted V_2 of training and testing data sets by each velocity network

The error of the predicted V_2 was lower than that of the predicted V_1 for all architecture networks. The three target values of V_2 were 1760 m/s, 4305 m/s, and 3441 m/s. They were the velocities of the bottom layer of 2-m, 6-m, and 10-m interface depth data sets. For two-layer architecture network, the mean error of the 72-12-2, 72-24-2, and 72-36-2 networks were -1.4 %, 3.4 % and 3.2 % respectively. Their standard deviations of error were 8.2 %, 2.6 %, and 4.9 % respectively. The 72-12-2 network was not a good network for estimating V_2 because its standard deviation of error was the largest among the two-layer architecture network even though its mean error was the lowest. The 72-24-2 network was likely to be the best network among the two-layer architecture network because of its lowest standard deviation of error.

The error in the estimated V_2 of the three-layer architecture networks was larger than that of the two-layer architecture networks. The mean errors of the 72-10-10-2, 72-10-15-2, and 72-15-10-2 networks were -5.3 %, 14.1 %, and 17.0 % respectively. Their standard deviations of error were 14.2 %, 12.7 %, and 17.3 % respectively. Among these three-layer architecture network, the 72-10-10-2 network appeared to be a good three-layer architecture network in determining the bottom layer velocity of an irregular interface because of its significantly lowest mean error and its standard deviation of error was in the same range with others.

By considering error of both predicted V_1 and V_2 of the testing data sets together, the mean error of the two-layer architecture networks was smaller than that of the three-layer architecture network, Fig.3.17. The absolute value of mean error for all of the studied networks was between 2.2 % and 21.1 %, whereas their standard deviation of error varied between 15 % and 32 %. The 72-12-2 network with its mean and standard deviation of error of 6.0 % and 15.3 % respectively was likely to be the best architecture network in determining top and bottom layer velocities because of its lowest in standard deviation of error and its mean error was less than 10 %.



. ***Figure 3.17*** Predicted V_1 and V_2 of testing data sets by each velocity network

The overall mean error of both estimated V_1 and V_2 was greater than that of the estimated V_2 alone in all studied networks. It was about 2 to 5 times greater than the mean error of V_2 estimated by two-layer networks, Fig. 3.16 and 3.17. Large error in V_1 caused by testing data set of shallow interface was probably responsible for large deviation of overall mean error from the mean error of V_2. If this testing data set were removed, the overall mean error of all studied networks would be reduced. The overall means error of all predicted velocity without data set of average 2-m interface depth was shown in Table 3.1 below.

Table 3.14 The overall mean error without data set of average 2 m interface depth

Network architecture	Overall error (%)	
	Mean	Standard deviation
72-12-2	-0.3	8.5
72-24-2	-9.5	19.4
72-36-2	3.0	6.6
72-10-10-2	-16.3	18.9
72-10-15-2	3.2	18.5
72-15-10-2	17.4	22.7

The overall error without data set of shallow interface depth showed that the mean and standard deviation of error of the 72-12-2 and 72-36-2 networks were less than 10 %. They were probably good architecture networks employed in estimating velocities of the top and bottom layer of ground whose interface was irregular.

The velocity network of the dipping interface and that of the irregular interface behaved differently. In the dipping interface case, the velocity network could estimate top ground layer velocity, V_1, more accurate than the bottom ground layer velocity, V_2. The other way round was observed with velocity network of irregular interface. This was probably because there was longer refracted segment than the direct segment on travel-time curve. By examining travel time curves (t-x graph) of training and testing data, most data sets actually had the refracted segment longer than the direct segment.