Application and study of seismic isolation in the Kunming new airport terminal building

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ABSTRACT :
The main building, i.e. the kernel area of the Kunming new airport terminal is an import and complex structure, and it is located in the area with high seismic risks. To this end, seismic isolation techniques were applied to the building structure. The seismic isolation layer was set between the basement and platform of piles, and three kinds of isolation devices, i.e. natural rubber bearing, lead rubber bearing, and viscous damper were adopted. Analysis and design details are presented in the paper. The analysis and design results suggest that satisfactory seismic isolation effects can be achieved for the important and complex structure.

KEYWORDS:
Seismic Isolation, Kunming New Airport, Natural Rubber Bearing, Lead Rubber Bearing, Viscous Damper

1. INTRODUCTION

The new Kunming Airport, located at the northeast direction of Kunming city, is a large scale airline hub. Fig 1 gives the bird's-eye view of the terminal area. The terminal is arranged between two air plane runways, using a centralized structural form. Those in front of the terminal are the entrance viaducts and the open style parking building. The parking building is a two story structure constructed underground, and its roof serves as the front landscape of the terminal. The terminal consists of the main building, i.e. the kernel area, the front east and west corridors, the central corridor, and the back east and west Y-shape corridors. The building area of the terminal is 460,000m2, and the lengths are 855.1m and 1134.8m in north south and east west directions, respectively. The highest position at the south ridge of the main building is 72.75m, and the lowest position at the roof of the front east and west corridors is 15.23m. Fig. 2 gives the elevational view of the terminal.

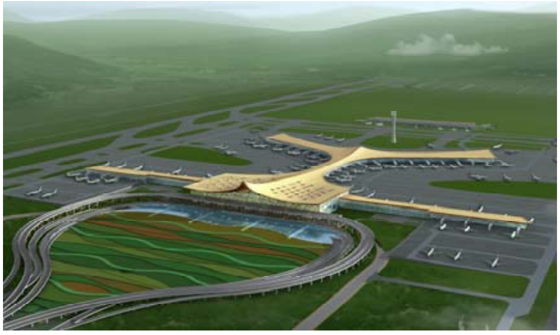


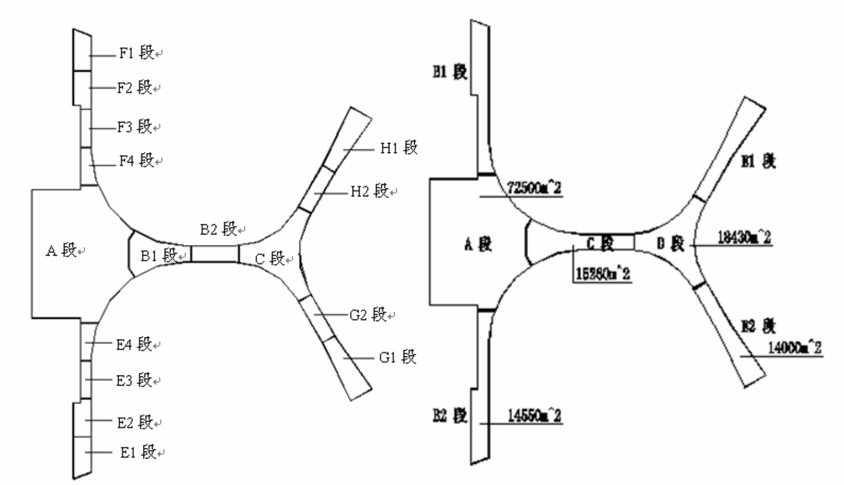
Figure 1 Bird's-eye view of terminal area

Figure 2 elevational view of terminal building

The main building has three overground stories (four stories in some local area) and three underground stories. The third story with the elevation level of 10.4m is the ticket hall and safety checking area for domestic departure. The second story with the elevation level of 4.8 is the luggage collecting and safety checking areas for international departure, office area, etc. The first story with the elevation level of +/-0.0 is the passages, the safety checking area for arrivals, the luggage distribution area, the office area, etc. The underground stories are mainly for the luggage transportation system, and the electromechanical devices. The elevation levels of the underground three stories are -5.0m, -10.0m, and -14.0m, respectively.

2. STRUCTURAL SYSTEM

The main structure of the terminal adopts reinforced concrete frame. The column grids are 12m×12m for most areas, and 12m×18m and 18m×18m for the rests. As shown in Fig. 3, the entire reinforce concrete structure can be divided into 16 areas. The roof and its supporting system are steel structures. The shape of the roof is a hyperboloid surface constructed by quadrangular pyramid space trusses. The supporting system uses color strip, pyramid shape steel pipes, rocking columns with varing box section and braces between columns. Also as shown in Fig. 3, the roof can be divided into 7 areas.



(a) Division of reinforced concrete structure (b) Division of steel structure

Figure 3 Division of structure system

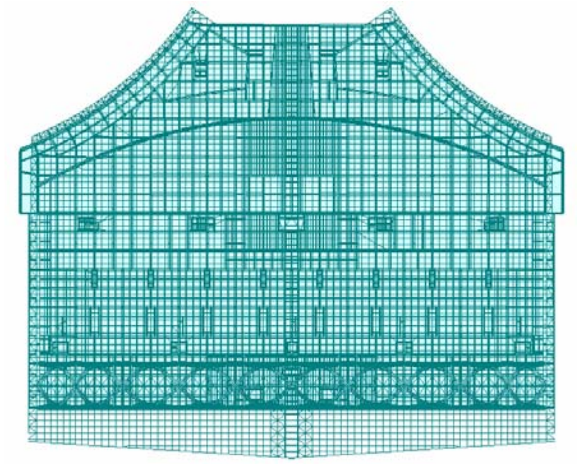
Area A is the kernel area. It has lengths of 325m and 257m in east west and north south directions, respectively. The area is a reinfoced concrete structure having three overgound stories and three undergound stories. Figs. 4 is the three view of the structure. Tables 1 and 2 give the foundamental parameters of the structure. The roof and its supporting system is a steel structure. The distinguishing character of the supporting system is that it uses seven color strips. The structure system is rather complex with unsymetric stiffness in both longititutive and transverse directions.

Table 1 Fundamental parameters of reinforced concrete structure

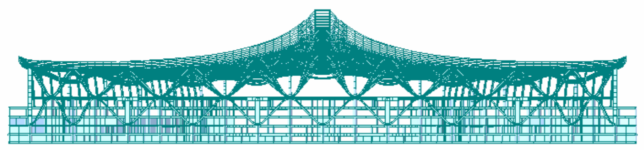
Story	Elevation level (m)	Story height (m)	Story Mass (ton)
3F	10.4	0.0	175660
2F	4.8	5.6	157433
1F	0.0	4.8	78461
B1	-5.0	5.0	226237
B2	-10.0	5.0	130535
B3	-14.2	4.2	197384

Table 2 Fundamental period of reinforced concrete structure

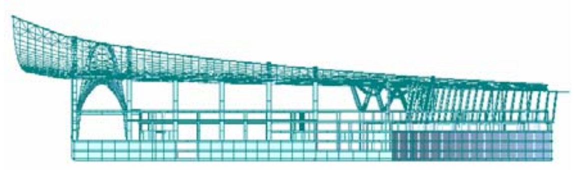
Direction	Period（s）
X Direction	0.75
Y Direction	0.78



(a) Planar view



(b) Elevational view



(c) Side elevationary view

Figure 4 Three view of kernel area structure

3. TERMINAL LOCATION AND REASON TO ADOPT SEISMIC ISOLATION

The Kunming new airport is located at the area close to west end of the Xiaojiang seismic belt, which is in north south direction. As shown in Fig. 5, the terminal buildings is just 12km away from the Xiaojiang fault. Prmarily due to existence of the Xiaojiang seismic belt, seven earthqakes with mangnitudes over 4.7 has been recorded from 1599 to present in the zone. Among the seven earthquakes, 4 of them have magnitudes of 5 to 5.9, 2 of them have magnitude of 6 to 6.9, and1 of them have magnitude over 8. The epicenter of the most earthaukes are on east side. According to the predition of chinese earthquake orgnization, Kunming new airport is located in a postion prone to be shaked by a earthquake with a mangnitudes over 7 before 2020.

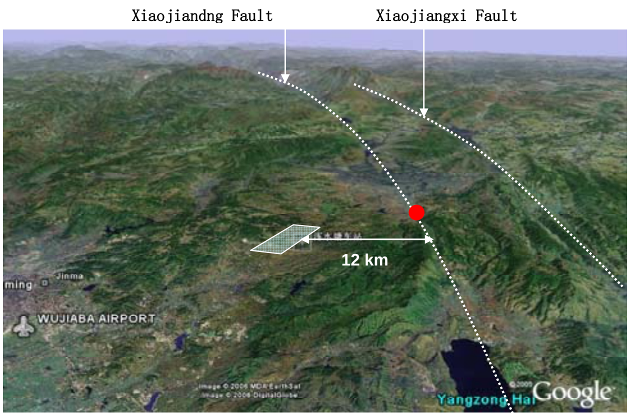


Figure 5 Earthquake faults close to terminal

In the world, quite a few seismic isolation structures have been applied sucessfully to larege scale airport in the zone with large earthquake intensity. For instence, the Los Angeles internatinal airport of the US is just 5km awary from the San Andres fault, which is a famous active fault having a length of 965m. in this centuary, 14 earthqukes with mangnitudes over 6 have happened in area. Among them, the largest was 1906 earthquake with a magnitude of 8.3. Three earthquakes with magnitudes of 7.6, 6.7 and 6.6, respecively, have happened. Los Angeles international airport is one of largest airport in the world (ranked 14). It has a capacity of handling 34,630,000 passengers, and 636,000 ton cargos. It was selected as the best international aiport in the US in 2005. The main terminal building of the Los Angeles international airport has a length of 350m, and a width of 150m. It adopts innovative seismic isolation techniques, and it is designed to resist earthakes with magnitudes of 8 and happened at the closest position on the fault. The building is the lagest seismic isolation structure in the world, and the seismic isolation techniques significantly decrease its structural cost, Antalya International Teminal building No.1 also adopts seismic isolation, using 130 FPS base-isoltion bearings. Therefore, uisng base-isolation for the terminal building of the new Kunming ariport is feasible and necessary.

4. ARRANGEMENT OF SEISMIC ISOLATION LAYER

Seismic isolation layer are commonly set at the column top to support the structure roof, close to ±0.00, or at the top of the basement. However, in this particular project, the steel roof using space trusses is relatively light, and the weight of the roof is just 1/25 of the entire sturcture, indicating that the roof isolation system will not be very effective for the structure. Also, the structure has a large number of open holes on the first floor due to the requirment of buiding fuctions, so it is not apropreciate to apply seismic isolation layer close to ±0.00 either. Finally, seismic isolation layer is set below the basement. Such a arrangment does not affect the funcationality of the building, and can also have seismic isolation effects. As shown in Figs. 6 and 7, the seismic isolation layer is set at the elevation level of -14.2m, i.e. the postion between the underground third story and foundtion top. The seismic isolation layer consists of lead rubber bearings, natural rubber bearings, and viscous dampers. The number of lead rubber bearings is determined according to the horizontal sesimic reduction factor, and the vicous dampers are used to control the displamcent of the seismic isolation layer when subjected to large earthquakes.

The arrangement details of the seismic isolation layer are shown in Figs. 8 to 10. Fig. 8 gives the arrangement of rubber bearing, including 535 lead rubber bearing with 1000mm in diameter, and natural rubber bearing with 1000mm in diameter. The parameters of the rubber bearings are given in Table 3. Figs. 9 and 10 are the arrangement of viscous damper in X and Y directions, respectively. Specifically, 54 viscous dampers are arranged in both north south and east west directions, the damping coefficient is 1500kN/(m/s)0.4. According to the arrangement of the isolation layer, the periods of the isolation structure when subjected to small earthquakes are 2.36s and 2.33s in X and Y directions, respectively, and those when subjected to large earthquakes are 2.97s and 2.96s in X and Y directions, respectively.

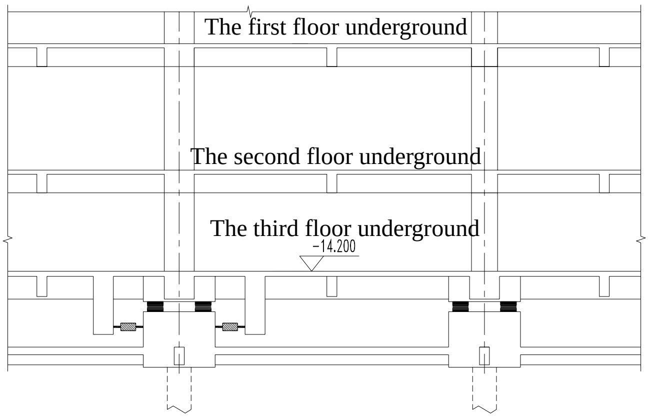


Figure 6 Position and construction of seismic

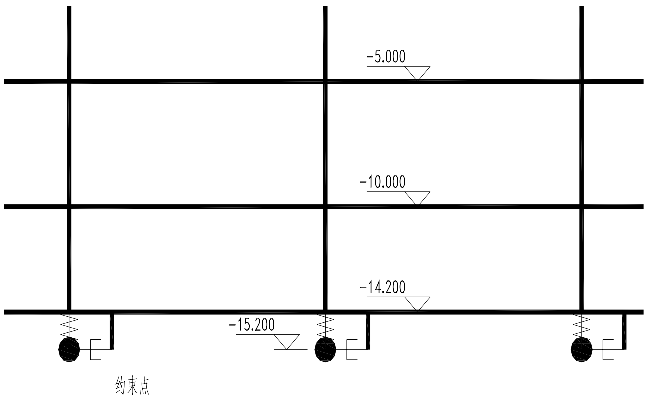


Figure 7 Analysis model of seismic isolation layer

Table 3 Parameters of rubber bearing

Name	Shearing modulus (N/mm2)	Type	1st shape factor	2nd shape factor	Effective area (cm2)	Horizontal stiffness (kN/m)			Vertical stiffness (kN/mm)
						Pre-yielding stiffness	Yielding force	Post-yielding stiffness	
RB1000	0.55	NRB	38.0	5.4	7834	2540			5779
LRB1000	0.55	LRB	41.7	5.2	7854	28900	208	2670	6030

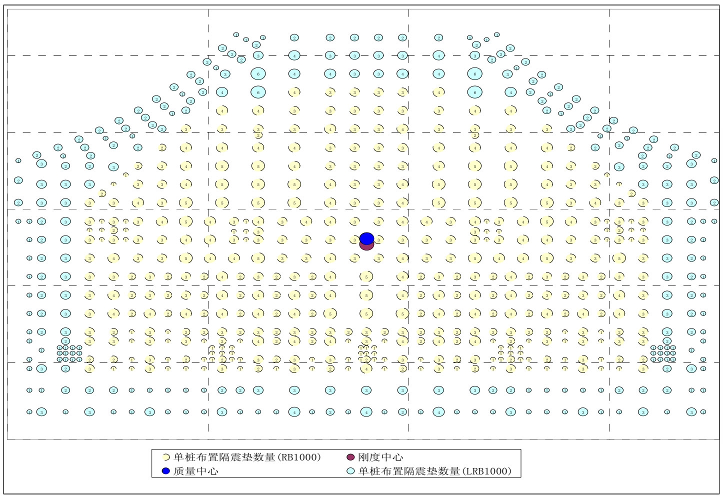


Figure 8 Arrangement of rubber bearings

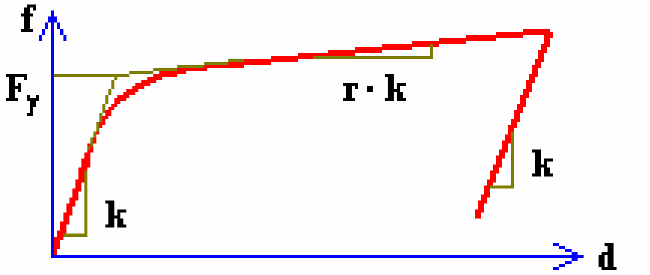


Figure 11 Analysis model for lead rubber bearing

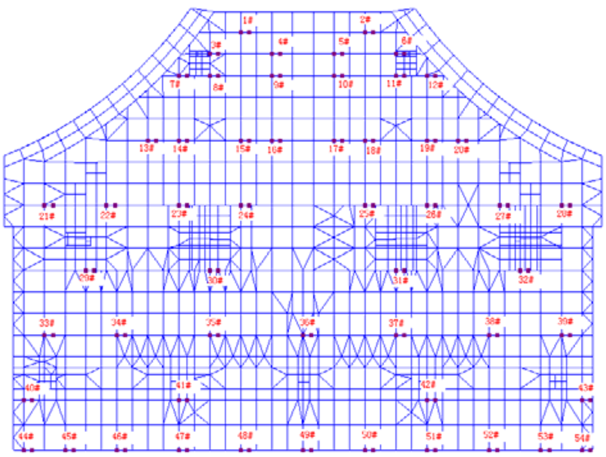


Figure 9 Arrangement of viscous damper in X

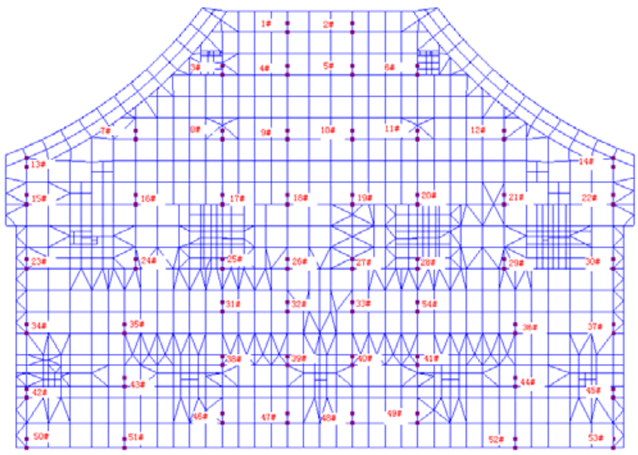


Figure 10 Arrangement of viscous damper in Y

5. ANALYSIS MODEL AND METHODOLOGY

Provision 12.2.2 of Chinese code for seismic design gives the design methods for seismic isolation structure. In this project, the roof is a large span steel structure, and its supporting system is also a steel structure. In addition, the roof structure is rather complex, and the stiffness of the supporting system in Y direction is rather weak. On the other hand, the reinforced concrete structure below is also complex, and some floor areas are significantly weakened due to the open holes. Therefore, the entire structure system is a complex structure system, thus time history analysis is mandatory for its design according to Chinese seismic code.
The analysis model is constructed for the entire structure, including the reinforced concrete below, roof supporting system, the roof structure, and the seismic isolation layer. The seismic isolation layer consists of natural rubber bearings, lead rubber bearings, and viscous dampers. Linear elastic constitutive model is adopted for the natural rubber bearings, nonlinear constitutive model is used for the lead rubber bearings (Fig. 11), and the Maxwell model is used for the viscous dampers

Several cases with different inputs were considered in the time history analysis for different purposes:
(1) Horizontal excitation in one direction using seismic reduction factor in reference to Chinese seismic code.
(2) Horizontal excitation in two directions to calculate displacement in large earthquakes.
(3) Three direction excitation (X:Y:Z= 0.85:1:0.65 or 1:0.85:0.65) to calculate the ultimate tensile and compressive forces of the rubber bearings.

Table 4 Shearing forces ratio of seismic isolation to non-isolation structures in X direction

		STORY-2	STORY-1	STORY1	STORY2	STORY3
Non-isolation	Jianyuan 118	473500	409100	365300	348500	234500
	Jianyuan 202	563400	514900	401800	384400	261900
	Artificial motion 61	575800	517600	369400	337400	217000
	Artificial motion 62	590800	514800	339000	351000	271800
	NORIDGE	615400	575600	479200	425900	255500
Seismic isolation	Jianyuan 118	171400	154500	118100	101200	58420
	Jianyuan 202	159700	142800	108800	95940	61810
	Artificial motion 61	179500	149800	119400	104100	61510
	Artificial motion 62	213700	182900	127300	105600	58690
	NORIDGE	228600	196500	146200	124900	72410
Non-isolation	Average	563780	506400	390940	369440	248140
Seismic isolation		190580	165300	123960	106348	62568
Shearing force ratio	Average	0.34	0.33	0.32	0.29	0.25

Table 5 Shearing forces ratio of seismic isolation to non-isolation structures in Y direction

		STORY-2	STORY-1	STORY1	STORY2	STORY3
Non-isolation	Jianyuan 118	406000	346700	275000	248500	178100
	Jianyuan 202	425000	366300	302900	306600	220900
	Artificial motion 61	509600	447600	348800	343200	245700
	Artificial motion 62	445700	371500	302700	301900	225300
	NORIDGE	432200	381400	283700	286800	200300
Seismic isolation	Jianyuan 118	173400	156600	119400	101900	56280
	Jianyuan 202	157800	141000	109700	102900	64460
	Artificial motion 61	180300	151800	121400	105900	61150
	Artificial motion 62	207000	176000	121000	105300	60300
	NORIDGE	228600	197600	146400	124400	69490
Non-isolation	Average	443700	382700	302620	297400	214060
Seismic isolation		189420	164600	123580	108080	62336
Shearing force ratio	Average	0.43	0.43	0.41	0.36	0.29

6. ANALYSIS RESULTS

Time Analyses are conducted for both small and large earthquakes, and the results are as follows:

6.1 Results for Small Earthquake

Tables 4 and 5 give the shearing forces of seismic isolation and non-isolation structures when subjected to small earthquakes and the ratios of the former to the latter as well. The results are given for each story. It is found that the design earthquake intensity can be decreased by 1 grade according to chinese seismic code.

6.2 Results for large Earthquake

(1) Displacement of seismic isolation layer
The displacement response of the base isolation layer is given in Table 6 for different earthquake records.

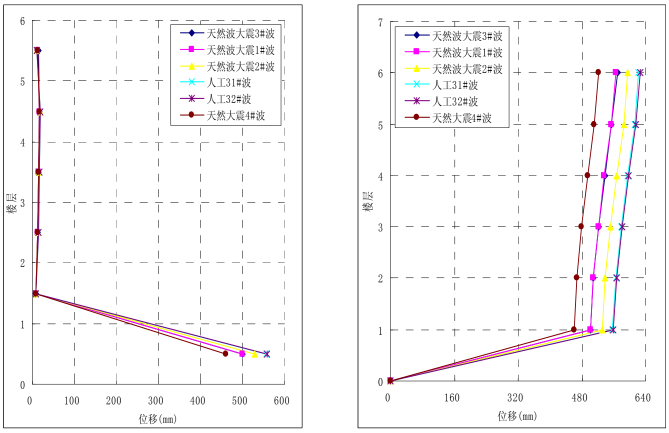
Table 6 Displacement of base isolation layer

Input ground motions	X:Y=0.85:1	X:Y=1:0.85
Large earthquake record 31	587mm	587mm
Large earthquake record 32	579mm	579mm
Large earthquake artificial record 1	510mm	460mm
Large earthquake artificial record 2	512mm	507mm
Large earthquake artificial record 3	548mm	562mm
Large earthquake artificial record 4	482mm	455mm
Average	536mm	525mm

(2) Interstory drift when subjected to large earthquakes
The story displacement and interstory drift is given in Fig. 12. It is found that the maximum interstory drift is 18mm, corresponding to an interstory drift angle of 1/294.

7. CONNECTION DETAILS FOR ISOLATION DEVICES

As shown in Figure 13, the base-isolation layer is set above the platforms of the piles. Downward rest piers are constructed below the base floor of the superstructure, and the viscous dampers are installed between the platforms of the piles and the downward rest piers.



(a) Story displacement (b) Interstory drift

Figure 12 Story displacement and interstory drift

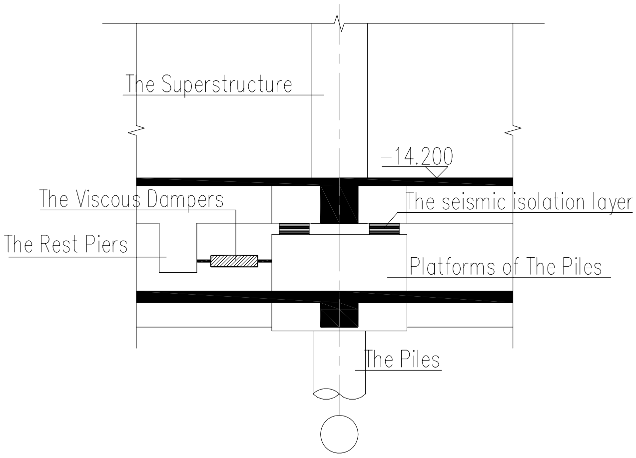


Figure 13 Connection between isolation devices and

1 to 6 rubber bearings need to be installed under each column according to the axial forces sustained by the column. As shown in Fig. 14, enough spaces are needed between rubber bearings for the convenience of installation. Figure 15 gives the connection details between rubber bearings and the reinforced concrete structure. During the installation, bolts and steel bars are connected by using mechanical coupling sleeve.

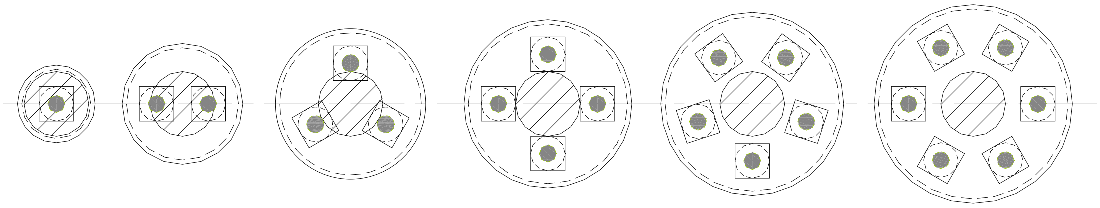


Figure 14 Arrangement of rubber bearings

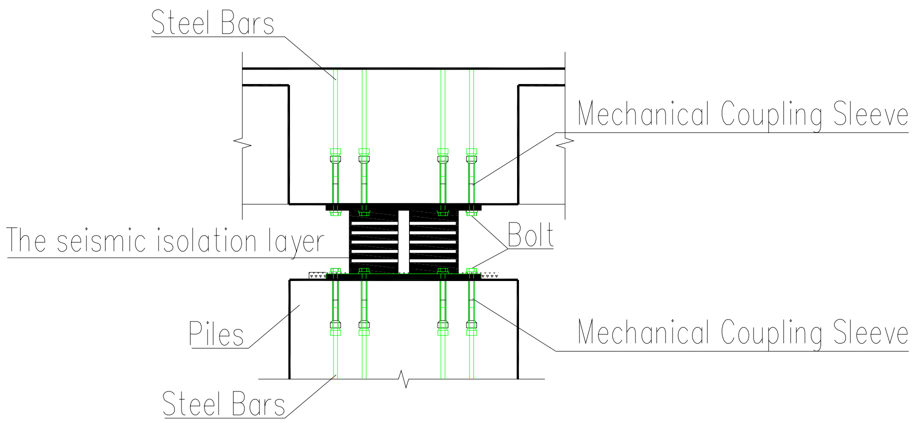


Figure 15 Connection details of rubber bearings to reinforced concrete structure

8. CONCLUSIONS

The kernel area of Kunming new airport is designed by using seismic isolation techniques. The major conclusions are summarized as follows:

(1) The isolation technique is applicable to the structure, and seismic isolation target can be achieved.
(2) Although the structure is a complex structural system, especially its roof supporting system is relatively flexible compared to the reinforced concrete below, satisfactory seismic isolation effects are still achieveable.
(3) The displacment of seismic isolation layer is small when subjected to both themal and wind load.
(4) The superstucture above isolation layer can be designed accordign to the earthquake intensity adjusted by considering isolation effects, and conventional design mehtod is applicable for the design. However, Provision 5.2.5 of chinese code for seismic design should be satisfied, and the desgin results should be verified by the time hisotry analsyis.

REFERENCES

Tang J., Liu Z. (1993). Base-isolation for building structures. Huazhong institute of technology press, China. (in Chinese)
Zhou F. (1997). Seismic control in engineering structures. Earthquake engineering press, China. (in Chinese)
Zhou S., Yan W., Yang R. (2002). Seismic isolation and vibration control for building structures. Journal of Building Structures 23; 2, 2-12, 26. (in Chinese)